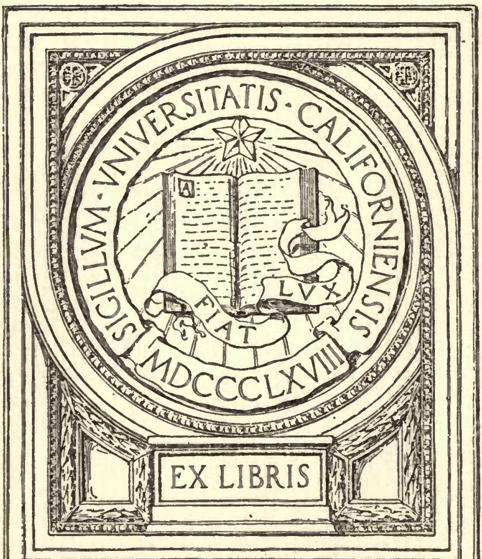
ECONOMIC WOODS OF THE UNITED STATES

SAMUEL J. RECORD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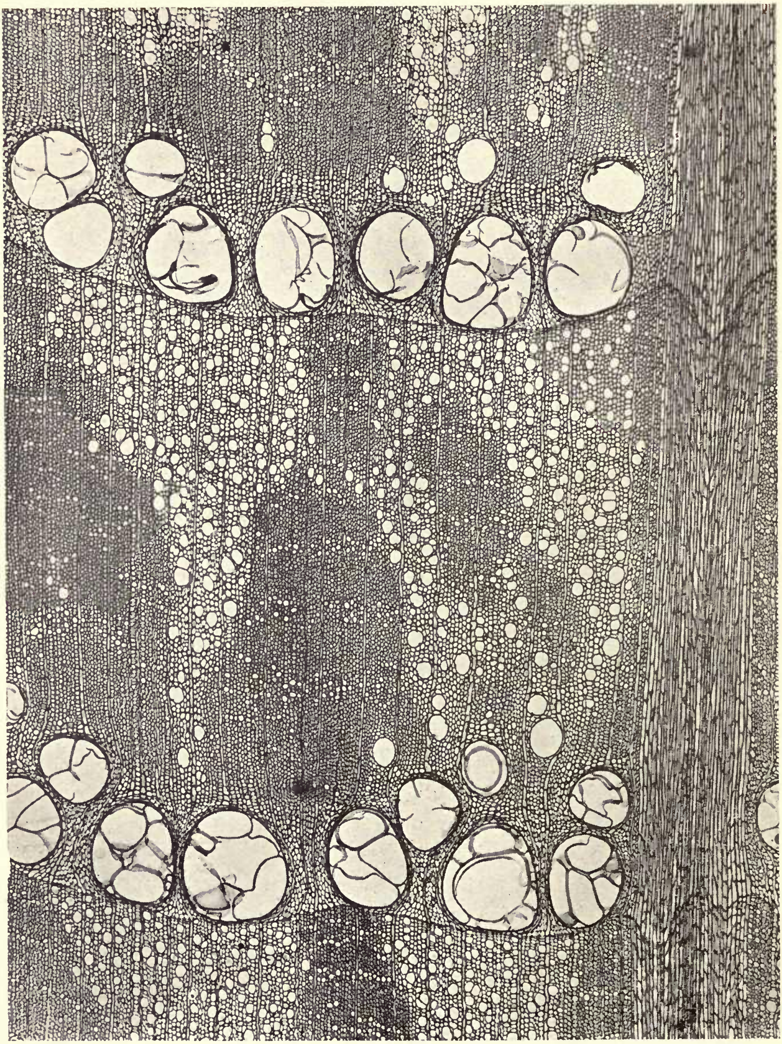

Quercus alba (white oak): cross section through one entire growth ring and portions of two others. Note large pores in early wood filled with tyloses and abruptly diminishing in size toward late wood. Small pores thin-walled and in fan-like groups. Note "dipping in" of the outline of the growth ring where it crosses the large ray at the right × 35.

Identification

OF THE

Economic Woods of the United States

Including a discussion of the Structural and Physical Properties of Wood

BY

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PREFACE TO THE SECOND EDITION

The chief differences between this edition and the first (1912) are as follows: (1) The Key has been entirely rewritten and rearranged, several new woods are included and more of the common names are given; (2) the lists of references and the general bibliography have been brought up to date; (3) an Appendix has been added which amplifies some of the subject matter of Part I, and also includes considerable new data on wood structure.

In grouping the woods in the Key more attention has been given to their general similarity than to special features, thus bringing together for effective contrast the kinds which are most likely to be confused in practice. Attempt has been made to have all of the descriptions comparable and, so far as permissible, to make the gross characters the basis for separation. The microscopic features are printed in smaller type than the others, to avoid confusion and to simplify the use of the Key.

It is comparatively easy to make a key for a given lot of wood specimens, but to take into account the range of variation of each wood is an extremely difficult task. Such a key must be the result of growth, of the accumulation of years of investigation and experience, and must always be subject to revision as new data and new material become available. To this end the author would enlist the coöperation of all readers of this book.

Samuel J. Record.

INTRODUCTION

As the available supply of the standard kinds of timber has decreased, woods have appeared on the market which formerly were considered worthless. In some instances the new woods are sold under their own names, but usually they are employed as substitutes for more expensive kinds, or sold in indiscriminate mixture. It thus becomes a matter of great importance that foresters, timber-inspectors, and wood-users be able to distinguish the woods with which they deal. The number of such woods is so large, and their resemblance often so close, that one can no longer depend upon distinguishing them through mere familiarity with their general appearance. To identify woods it is necessary to have a knowledge of the fundamental differences in their structure upon which the points of distinction are based.

The literature bearing directly upon this subject is very limited, and such information as exists is for the most part distributed throughout a considerable number of publications and not readily available. Teachers and students of wood technology are seriously handicapped by the lack of suitable text-books or manuals. It is in an attempt to supply in small part this deficiency that the writer has prepared for publication a portion of the material given in one of his courses in Forest Products at the Yale Forest School. While it is designed primarily as a manual for forestry students, it is hoped that it will also aid others in the study and identification of wood.

Part I deals briefly with the more important structural and physical properties of wood. The structural properties are based upon the character and arrangement of the wood elements. Under this head are considered: (*a*) the external form of the tree in its various parts; (*b*) the anatomy of the wood; (*c*) abnormal developments or formations; (*d*) relation of these properties to the usefulness of wood; and (*e*) their importance in classification. The physical properties are based upon the molecular composition of the wood elements. Under this head attention is given to (*a*) the properties manifest to unaided senses, viz., color, gloss,

odor, taste, and resonance; (*b*) those determined by measurement, viz., density, weight, water content, shrinkage, swelling, warping, and hygroscopicity; (*c*) relation of these properties to the usefulness of wood; and (*d*) their employment to some extent as aids to identification.

In Part II attempt is made to use the details of Part I in the construction of an artificial classification of the economic woods of the United States. Unimportant species have in some cases been included where it was felt that their presence would not lead to confusion. This classification has been prepared with two objects in view: (1) for use in practice as a key for the identification of unknown specimens; (2) for use in the laboratory as a basis for the comparative study of known specimens.

As far as considered practicable, the distinctions in the key are based on macroscopic features, those readily visible to the unaided eye or with the aid of a simple lens magnifying 10 to 15 times. Owing to the great variation of wood it is usually unwise to rely upon single diagnostic features, and for this reason the descriptions have been extended to embrace all or most of the important characters so far recognized. This method also permits ready arrangement of the key or the fitting into it of additional woods.

In the woods of many genera the structural variations apparently are not sufficiently distinct and constant to assure specific identification. Good examples of this are afforded by the woods of *Pinus*, *Quercus*, *Hicoria*, and *Populus*, where it is usually difficult and very often impossible to do more than separate them into groups. Accurate knowledge of the botanical and commercial range of each species will often serve as a basis for further subdivision of a group in which other distinctions are apparently wanting.

In preparing a specimen for careful examination either with or without a lens it is highly desirable that a very smoothly cut surface be obtained. If the knife used is not sharp, the cut surface will be rough and the details of structure obscured. Cross sections are, as a rule, the most valuable for comparative study, and in making them it is very important that the plane of section be as nearly as possible at right angles to the vertical axis of the specimen.

A compound microscope is necessary for the study of the minute anatomy of wood. Sections for immediate observation

may be cut free-hand with a sharp pocket-knife or razor and mounted in water. To avoid air bubbles in the sections small pieces of the specimens should be boiled prior to sectioning. It is not important that such sections be of uniform thickness, since a thin edge will usually exhibit the essential details.

Much better results can be obtained by the use of a microtome. Penhallow recommends a table microtome and a plane blade mounted in a heavy wooden handle of such a form as to provide a perfectly firm grip. For fine work, however, a sliding microtome specially constructed for sectioning wood is best. Success depends largely upon the sharpness of the knife and the rigidity of the apparatus.

Considerable care should be exercised in the selection of material for sectioning. Small blocks of about a quarter-inch cube should be cut from green material, or from the interior of dry pieces. The faces of the blocks should represent sections which are as nearly cross, radial, and tangential as possible. Blocks of the lighter woods can be softened sufficiently by boiling them in water until thoroughly saturated. The process may be hastened by interrupting the boiling by additions of cold water. In the case of the harder woods, however, it is a good plan to place the small blocks, after boiling, in a solution of hydrofluoric acid for a period varying from ten days to three weeks, the strength of solution and the duration of immersion depending upon the hardness of the wood. After removal from the acid the blocks should be thoroughly washed and then placed for several days in glycerine, after which they are ready for sectioning. The sections may either be mounted unstained in glycerine or stained in the usual way and mounted in balsam. For ordinary work unstained glycerine-mounts afford the most satisfactory results, since the natural colors are preserved. (For more detail, see references below.)

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The best idea of the form and size of the individual cells is gained from studying macerated material. This is readily obtained by placing small pieces of wood in a test-tube together with a number of crystals of potassium chlorate, and adding enough nitric acid to cover them well. After the wood has turned white the solution should then be poured off and the material washed thoroughly in water. This action may be hastened by warming. It is then easy to remove a small portion of the mass to a slide where it can be dissected with a couple of needles and studied under the microscope.

The writer desires to acknowledge his indebtedness to Prof. James W. Toumey for much of the data upon which this work is based; to Mr. Clayton D. Mell for many helpful suggestions and criticisms; and to Mr. Charles J. Heller for the loan of a set of wood sections from which the photo-micrographs were made by the writer at the Forest Products Laboratory, Madison, Wisconsin.

PART I

STRUCTURAL AND PHYSICAL PROPERTIES OF WOOD

GENERAL

Wood of a timber-producing tree may be considered under three general heads, viz., *root*, *stem*, and *branch*. The relative proportion of the three classes of wood in a tree depends on the species, the age, and the environmental conditions of growth. The woody portion of stem and branch has, within certain limits, the same structure. Branches are of less technical value because of their irregular shape and small dimensions. The latter is due to the fact that the number and thickness of the layers of growth are less and the wood elements smaller than in the bole.

Wood of roots always differs somewhat from that of the stem in form, structure, and distribution of the elements; the growth rings are narrower, the elements have wider lumina, and the wood is as a rule lighter, softer, and more porous. Roots, with occasional exceptions, are a very subordinate source of wood in America.

Stem wood, on account of its more desirable dimensions and shape and its greater uniformity, is of the greatest utility and value. The form and character of the stem are of greater importance than the relative volume; with few exceptions the more nearly straight and cylindrical and the freer from limbs, knots, and defects, the greater are its technical properties and value. These properties are largely determined by the age of the tree and the inherent characteristics of the species, though affected by environment. Straightness and clearness are materially influenced by density of stand.

A woody stem, branch, or root is composed of three unlike parts (Fig. 1). Through the central portion runs a narrow cylinder of soft tissue, the *pith*. On the outside is *bark*. Between these two and making up the bulk of the structure is the *wood* or *xylem*. The wood, particularly in old sections, usually shows a central

colored portion, the *heartwood*, and a nearly colorless outer border, the *sapwood*. In fresh-cut green sections the sapwood is further differentiated by its greater moisture content.

Indigenous arborescent plants are readily separable into two

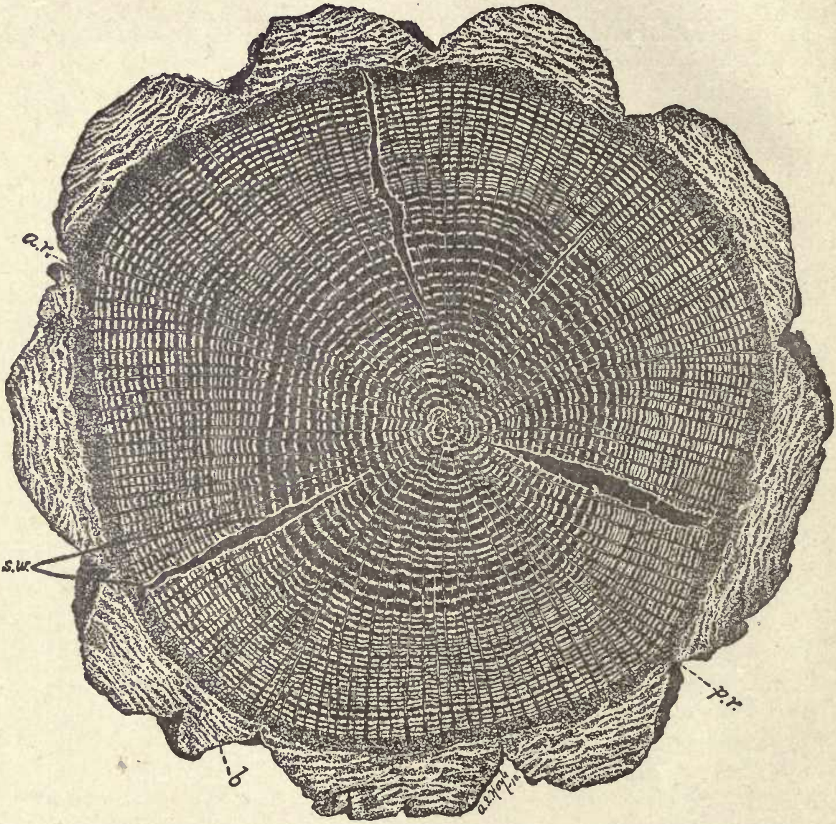

FIG. 1.—Cross section of stem of *Quercus prinus* (chestnut oak); *b*, bark showing outer and inner portions; *s. w.*, sapwood; the darker inner portion is heartwood; *a. r.*, annual or growth ring; *p. r.*, (pith) ray, a large number of which can be seen crossing the growth rings at right angles. Note season checks. Natural size. (From Bul. 102, U. S. Forest Service.)

great natural classes: I, Gymnosperms, and II, Angiosperms. Class I is further divided into two unequal groups: *Coniferæ* (13 genera), and *Taxaceæ* (2 genera). Class II embraces (according to

Sargent's "Manual of the Trees of North America"), Monocotyledons (2 families and 8 genera), and Dicotyledons (57 families and 149 genera). The Monocotyledons are of comparatively slight importance as sources of wood, and for that reason, as well as on account of their peculiar structure,* are omitted from the general discussion of wood and from the key.

The woods of the Gymnosperms are commonly referred to as "coniferous woods," "softwoods," and "needle-leaved woods." These terms are inexact since (1) the *Taxaceæ* do not bear cones; (2) many of the so-called "softwoods" (*e.g.*, *Pinus palustris*, *Pseudotsuga*, *Taxus*) are harder than many of the so-called "hard woods" (*e.g.*, *Populus*, *Salix*, *Æsculus*, *Tilia*); and (3) the contrast in the leaves is by no means always as great as the terms "needle" and "broad" would indicate. Common usage, however, has given these names sufficient definiteness for ordinary purposes, though they should be avoided where scientific exactness is desired.

PITH

The central portion of the young shoot, branch, and root is composed of loosely aggregated, mostly thin-walled, isodiametric, parenchymatous cells—the *pith*. It is usually of small diameter, does not increase in size after the first year, in fact, may even in some instances be compressed, and appears to be of only temporary utility to the tree. In some cases, according to Gris (*loc. cit.*), the cells remain active for several years, and alternately store and give up products of assimilation, especially starch and tannin, according to the periods of vegetation. In such instances the walls of the active cells are thickened and densely pitted.

The pith in woody stems of Gymnosperms is fairly uniform in shape, size, color, and structure; in Dicotyledons there is great variation. As to outline in cross section: it is star-shaped in *Quercus*, triangular in *Fagus*, *Betula*, and *Alnus;* ovoid in *Tilia*, *Fraxinus*, and *Acer;* circular in *Juglans*, *Ulmus*, and *Cornus*. In *Juglans* the color is black; in *Gymnocladus* it is red; in many others it is brown or gray. In *Rhus*, *Sambucus*, and *Ailanthus* the

* In adult stems of Monocotyledons the fibro-vascular bundles are scattered throughout the central cylinder instead of being disposed in a circle, as in the Dicotyledons. The bundles are closed and the tracheary tissue surrounds the phloem.

pith is comparatively large and conspicuous, often deeply colored. In *Magnolia*, *Liriodendron*, *Nyssa*, *Asimina*, and *Anona* there is often a more or less distinct septation of the continuous pith by plates of stone cells, while in *Juglans* there is decided septation but the diaphragms are not sclerotic, and the pith is not continuous between the disks. On account of these and other peculiarities the pith when present in a specimen of wood is frequently an aid to identification.

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BARK

Bark is the name commonly applied to that portion of a stem lying outside the cambium layer. Used in this broad sense, it is customary to distinguish an *outer* (dry) portion and an *inner* (living) portion. The structure of bark is highly complex and widely variable.

When shoots are first formed they are covered by a very thin layer of tissue, the *epidermis*. Beneath this is the *primary cortex* and the *pericycle*. The latter is commonly composed of two kinds of tissues, *thin-walled parenchyma* and *bast-fibres*. The bast-fibres may occur in isolated groups or form a continuous band around the stem. When in groups they are often closely associated with, but not really part of, the phloem of the vascular bundles. Bast-fibres are attenuated sclerenchymatous elements, with sharp ends simple or branched. Their function is to give strength to the stem and to protect the delicate tissues of the phloem. It is to them that many barks owe their great toughness and pliability.

Phloem, which is the outer portion of a *vascular bundle*, is in typical cases composed of *sieve tubes*, *companion cells*, and *phloem parenchyma*. In structure sieve tubes resemble vessels, but their walls are mostly delicate, non-lignified, colorless, cellulose mem-

branes. Between the ends of the sieve-tube segments (and sometimes between adjacent side walls as well) are thin plates dotted with pits, resembling a sieve. The pit membranes are finally absorbed, allowing free communication from one cell to another. Unlike vessels, the segments of the sieve tubes remain alive for a year or more, though they lose their nuclei. This unusual phenomenon may be due to some influence of the companion-cells or to associated parenchyma cells. The function of the sieve tubes is the vertical (especially downward) distribution of elaborated food materials. After the first year the cells usually become crushed by the pressure of the surrounding tissues, their places being taken by new cells generated by the cambium.

In addition to the structure just mentioned, many other elements and structures may enter the composition of the bark. Among these may be mentioned *resin ducts*, *latex tubes*, *stone cells*, *crystals*, *mucilage sacs*, and *tannin sacs*. *Bast rays* are also present, being continuous with the rays of the xylem. They increase in width uniformly and gradually as they recede from the cambium.

In practically all cases of growth in thickness the epidermis is destroyed at an early period and is replaced by *cork*. Cork is suberised tissue formed by a special meristem called *cork cambium* or *phellogen*, which originates in the epidermis or in the cells just beneath the epidermis. All parenchymatous cells, however, wherever located, appear to possess the ability to form cork. Wound surfaces are closed and healed by it, and diseased and dead parts are isolated from those in living condition.

The formation of cork cambium in the bark usually occurs during the first year's growth of the stem. As a result of its activity a layer of cork cells is generated on the outside, and frequently a layer of thin-walled parenchyma cells—the *phelloderm*—on the inside. Collectively these new tissues, including the cork cambium, are called the *periderm*. The effect of the development of cork is to cut off from the interior mass of tissue portions of the cortex, which dry up and are eventually thrown off as outer bark. This action may occur only once, as in *Fagus* and *Carpinus*, but usually is repeated, and successively deeper layers of the cortex and eventually of the pericycle and phloem are cut off.

In some species the successive formations of cork extend more or less uniformly around the stem, cutting off in each case an annular layer of cortex—sometimes called *ring bark*. In other species the successive internal layers are very irregular, and cut

off scale-like portions of the cortex—*scale-bark*. The results are subject to very wide variation.

In *Platanus* and *Taxus* the outer bark is shed annually in the form of comparatively large, irregular, thin flakes which, falling away, leave the surface smooth. In species of *Betula* thin, exfoliating layers are produced, marked with horizontal lines of *lenticels*. In many species of *Pinus*, the outer bark of mature trees is made up of small, irregular scales in very intricate pattern. In *Hicoria ovata* and *H. laciniosa* the outer bark peels off in long, flat, reddish-brown strips, while several other species of the same genus have bark that is not flaky. In a great many woody plants the layers of bark persist for many years, and, as the stem increases in size, become more and more cracked and furrowed. Such is the case in *Quercus*, *Robinia*, *Liriodendron*, etc. In *Sequoia*, *Juniperus*, *Taxodium*, and others of the Cedar group, the bark is characteristically fibrous. These examples are sufficient to indicate the wide variation in the bark and its importance as an aid to the identification of a specimen upon which any portion of bark remains.

The bark of many trees is of high technical value. A very great number are used for medicinal purposes. *Tsuga* and species of *Quercus* possess barks which contribute very largely to our tannin supply, upon which the leather industry is dependent. Some barks contain coloring principles; others (*e.g.*, *Hicoria ovata*) are highly valuable for fuel. Birch bark was formerly used for canoes. The inner barks of some woods (*e.g.*, *Tilia*) are sometimes used in manufacturing fibre cloth. The highly-developed corky layers of *Quercus suber* furnish the cork of commerce.

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PRIMARY WOOD

At the growing apex of a stem is an undifferentiated tissue composed of very thin-walled cells essentially all alike. This tissue is known as the *primordial meristem.*

Below the apex the primordial meristem becomes differentiated into three distinct parts, viz., (1) the *protoderm* at the outside, (2) the *procambium strands,* and (3) the *fundamental* or *ground meristem.* These three regions or tissues are themselves subject to further differentiation and are called *primary meristems.* The protoderm changes into the epidermis; the ground meristem into pith, primary rays, pericycle, and primary cortex; the procambium strands into vascular bundles, which are disposed in a circle around the pith and separated from each other by the primary rays. The *vascular bundles* are composed of three parts, an inner called the *xylem,* an outer called the *phloem,* and, separating the two, a thin layer of generative tissue, the *cambium.* These tissues, being the direct development of the cells of the procambium, are termed *primary* (*primary wood* — *protoxylem* and *metaxylem* — and *primary phloem*), in contradistinction to the tissues generated by the cambium, which are termed *secondary.*

Primary wood is relatively unimportant, though of scientific interest because of its peculiar structure, which in many ways differs from the other wood of the stem. Thus in Angiosperms, wood fibres are usually wanting and tracheids are not common in the primary wood, while in the secondary wood fibres are always present and tracheids commonly so. In Gymnosperms the vascular elements of the primary wood are indeterminate in length, marked with spirals and for the most part devoid of pits in their walls, while the corresponding elements in the secondary wood are of determinate length, rarely marked with spirals and always pitted.

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CAMBIUM

As previously stated, that portion of a pro-cambium strand which remains capable of division and generation is known as *fascicular* (*i.e.*, bundle) cambium, since it produces on the inner side wood or xylem, and on the outer phloem—collectively a fibro-vascular bundle. The cambia of the several bundles are later united into a continuous sheath, and the portion between the original bundles is termed the *inter-fascicular* cambium. The cambial layer sheathes the entire woody cylinder from root to branch and separates it from the cortex or bark. It is composed of a thin layer of delicate, thin-walled, vertically elongated cells filled with protoplasm and plant food. It is this layer that is torn when bark is stripped from a living tree. During vigorous growth, "when the sap is up," the cells of the cambium are particularly delicate, a fact taken advantage of in peeling poles, logs, and basket-willow rods.

The division and development of the cambial cells give rise to (*a*) a layer of new wood on the outside of that last produced; (*b*) a layer of new phloem on the inside of that last produced; (*c*) continuation of the medullary rays of both xylem and phloem; and (*d*) new cambium.

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SECONDARY WOOD

Tissues formed from cambium are termed *secondary*. Almost all of the wood of a stem is secondary wood, the small amount of primary wood being wholly negligible from a technological point of view.

The principal functions of secondary wood are (*a*) to provide

mechanical support for the tree; (*b*) to afford means for the ascent of sap from the roots to the foliage; (*c*) alternately to store up and to give back products of assimilation, particularly starch.

While the elements of secondary wood are subject to wide variation, they may for convenience be referred to three principal types, viz., (1) *vascular*, (2) *fibrous*, (3) *parenchymatous*. Between these groups are transitional and specialized forms whose reference to one or the other of these groups is often purely arbitrary. The classification may be extended as follows:

Vascular elements
- True vessels
- Tracheids
  - (wood) tracheids
  - ray tracheids

Fibrous elements
- Wood fibres
- Septate wood fibres

Parenchymatous elements
- Wood parenchyma
- Ray parenchyma

In the following table are shown side by side the important differences in the distribution of the elements in typical secondary wood of Gymnosperms and Dicotyledons. (See Appendix, p. 131.)

Gymnosperms	*Dicotyledons*
True vessels absent.	True vessels present.
Wood tracheids present and forming bulk of wood.	Tracheids present or absent; always subordinate.
Ray tracheids present or absent.	Ray tracheids absent.
Wood fibres absent.	Wood fibres present.
Wood parenchyma present (except in *Taxaceæ*), but usually subordinate.	Wood parenchyma present, and very often conspicuous.
Ray parenchyma present.	Ray parenchyma present.

From the above it is apparent that the wood of Dicotyledons is more heterogeneous in its nature than that of Gymnosperms, which is composed almost wholly of tracheids and ray parenchyma.

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VESSELS (see Appendix, p. 132)

Vessels are indeterminate, tube-like cell-fusions found in the wood of all indigenous dicotyledonous plants. In fact the absence of xylem vessels in woody Dicotyledons is a very rare phenomenon which, according to Solereder (*loc. cit.*, p. 1136), has been recorded only in the exotic genera *Drimys* and *Zygogynum* of the *Magnoliaceæ*, and *Tetracentron* and *Trochodendron* of the *Trochodendraceæ*.

Vessels arise from cambial cells which increase in size and, through the partial or complete absorption of their end-walls at the close of the process of thickening, become continuous in a longitudinal row. There is always a constriction at the place of fusion of the cells, thus plainly demarking the *vessel segments* (Plate VI, Nos. 3, 4, 6). The walls of contact of the segments of a vessel are sometimes (*a*) horizontal, but more often (*b*) oblique, and fit together exactly; or, again, they may be (*c*) oblique with a portion of the opposed faces united, the pointed and blind ends extending beyond the division wall, as in *Liquidambar* and *Quercus*. In (*a*) the perforation from one segment to another is *simple*, *i.e.*, with one round opening. In (*b*) and (*c*) the perforations are sometimes

simple and sometimes, especially in strongly inclined division walls, *scalariform*, that is, the opening is crossed with few to many bars in ladder-like arrangement. The bars are usually transverse to the longitudinal axis of the vessel. Both simple and scalariform perforations may occur side by side in the same wood, but usually one form prevails. These features have considerable diagnostic value. For example, the perforations are simple in *Acer*, but scalariform in *Betula* and *Cornus;* in *Æsculus* and *Tilia* they are mostly simple, but in *Liriodendron* and *Magnolia* scalariform, except in *Magnolia acuminata.*

Other characteristics of the vessels are the markings on their walls. In most cases they are abundantly pitted with bordered pits, except in contact with parenchymatous cells where the pitting may be either simple or bordered. (See PITS.) It is very common for vessels, particularly the small ones, to be marked with spirals on their interior walls (*e.g., Acer, Ilex, Tilia, Ostrya, Æsculus*). In *Liquidambar* only the pointed ends of the vessel segments are marked with spirals.

The function of vessels is to facilitate the ascent of water in the stem. Vessels lose their protoplasmic contents by the time their perforations are complete and become filled with air and water, or air alone. When their activity as water-carriers lessens they frequently become plugged with outgrowths from adjoining parenchymatous cells. (See TYLOSES.) In the heartwood of certain species (*e.g., Gymnocladus, Gleditsia, Guaiacum, Prosopis*) they become wholly or partly filled with gums or resins; in others, with carbonate of lime.

The length of vessels is usually very great, and doubtless often equals that of the whole plant. In width vessels exhibit great variation not only in different species, but also in different portions of the same growth ring. In some woods all of the vessels are small (*e.g., Tilia, Æsculus* [Plate VI, Fig. 5], *Populus, Salix*); in others they are mostly large (*e.g., Juglans*); very often, as in *Quercus* (Plate II, Figs. 5, 6), they vary from large (0.6 mm.*) and conspicuous to very small (0.1 mm.).

Vessels in cross section are called *pores*, and when this term is employed it will be understood to apply to cross sections exclusively. Pores are usually readily distinguishable from the adjoining elements by their larger size, though it is not always

* One millimetre is equal to about one twenty-fifth of an inch.

possible to tell small pores from cross sections of tracheids. In outline pores may be round, elliptical, or angular. The first two cases are the rule where the vessel walls are thick enough to resist the pressure of the surrounding elements. This is the case, for example, in the small pores of the red and live oaks (Plate II, Fig. 6), while in the white oaks (Frontispiece; Plate II, Fig. 5) the walls are thin and the pores angular in outline. Sometimes pores are disposed in rings or zones in the early wood of the growth ring, producing ring-porous woods (Plate III); in other cases they are scattered singly or in groups throughout the ring or arranged in radial or tangential rows, producing diffuse-porous woods (Plate VI). (See GROWTH RINGS.) In any case the largest pores are almost invariably in the first formed wood of the season. The distribution, size, form, and arrangement of the pores are characters of great importance in classifying woods.

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TRACHEIDS

Tracheids are elongated, spindle-shaped, fibre-like elements, determinate in length and characterized by bordered pits in their side-walls.

In the wood of Gymnosperms the tracheid is the dominant element, performing the dual function of conducting water and providing mechanical support for the tree. Bordered pits are mostly confined to the radial walls, except in late wood, and are most abundant near the ends of the tracheids and in one or two rows (Fig. 2, *D*). Seen in cross section, the tracheids are polygonal in outline, arranged in radial rows, and, near the periphery of growth ring, with very appreciable increase in thickness of the wall, reduction of the lumen, and tangential flattening (Fig. 8; Plate II, Figs. 1, 2, 4). In a few species, particularly *Pseudotsuga*,

Taxus, and *Tumion*, the tracheids are characterized by spiral thickenings on the inner wall.

TABLE I

LENGTH OF TRACHEIDS IN CONIFEROUS WOODS

Botanical Name	Average mm.	Maximum mm.	Minimum mm.
Abies balsamea	3.10	4.20	2.00
" concolor	4.65	6.00	2.75
" grandis	4.15	5.70	2.90
Chamæcyparis lawsoniana	3.60	4.35	2.55
" thyoides	2.10	2.80	1.45
Larix occidentalis	2.60	3.80	1.75
Libocedrus decurrens	4.00	4.70	3.00
Picea engelmanni	5.70	6.95	3.05
" rubens	2.95	3.65	2.50
" sitchensis	2.85	3.70	2.30
Pinus echinata	5.90	7.20	4.40
" edulis	1.95	2.55	1.50
" lambertiana	4.45	5.85	2.75
" monticola	4.40	5.45	2.75
" murrayana	2.65	3.70	1.80
" palustris	5.55	6.70	3.00
" ponderosa	3.30	4.00	2.50
" resinosa	4.05	4.80	3.20
" strobus	3.55	4.55	3.20
" tæda	3.10	3.90	2.55
" virginiana	2.75	3.95	1.75
Pseudotsuga taxifolia	2.70	3.30	1.80
Sequoia sempervirens	7.00	9.25	4.05
" washingtoniana	4.80	5.95	3.45
Taxodium distichum	4.70	5.80	3.65
Thuya occidentalis	2.00	2.40	1.40
" plicata	3.85	4.55	3.15
Tsuga canadensis	4.00	5.05	2.80
" heterophylla	3.05	3.65	1.75

In certain conifers, particularly *Pinus*, specialized forms of tracheids of a parenchymatous type are found associated with resin ducts and cysts. They resemble wood-parenchyma cells in form and function, but have bordered pits in their side and end walls. "Resinous tracheids" are ordinary tracheids with deposits of resin usually in the form of thin transverse plates.

The tracheids of broadleaf woods (Fig. 2, *E*) are subordinate

elements often entirely wanting. They are much smaller and less uniform in size and shape than in conifers, and are of most common occurrence in the immediate vicinity of vessels. Their ends are often curved, especially when they terminate just above or below a ray. The walls are usually comparatively thin and bear numerous bordered pits very irregularly distributed. Intermediate forms of tracheids are sometimes found which show distinct transition to the vessels in the detailed structure of their walls and in the occasional presence of perforations at the ends of the cells.

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WOOD FIBRES

Typical *wood fibres* (Fig. 2, *A*, *B*) are slender, spindle-shaped, sharp-pointed cells with thick walls and narrow cavities. They are further characterized by usually oblique and slit-like simple pits, or less frequently by small, indistinctly bordered pits. Wood fibres are not found in Gymnosperms, but are nearly always present in the wood of Dicotyledons.

Wood fibres are of two types, *septate* and ordinary (*non-septate*). The septate forms are divided by cross-partitions formed after thickening of the walls has begun. They are of limited occurrence and of relatively small importance. They are characteristic of *Swietenia mahagoni* and serve as one means of distinguishing the wood from that of certain others closely resembling it.

The ordinary forms are very common and are the principal source of strength, hardness, and toughness of broadleaf woods. While their function is largely mechanical, it is probable that they, especially those with bordered pits, play some part, as yet undetermined, in water transportation.

Wood fibres exhibit transitional forms from the typical to tracheids on one hand, and to wood-parenchyma strands on the

other. In structure and arrangement they exhibit variations of considerable taxonomic value. For example, in *Ilex* the fibres are rather thin-walled and marked with spirals and bordered pits, and closely resembling tracheids except for their greater size. In *Liquidambar* (Plate VI, Fig. 1) the fibres are mostly square in cross section and in rather definite radial arrangement. In

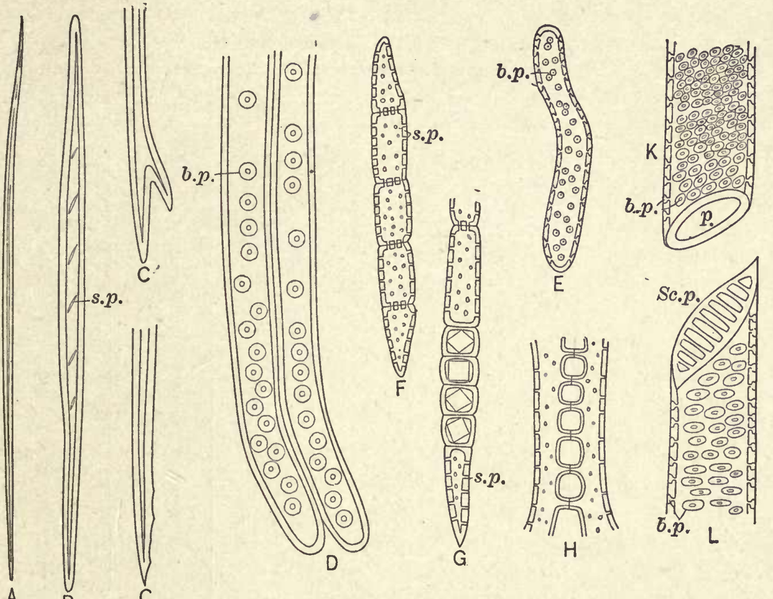

Fig. 2.—Typical Wood Cells. *A*, Wood fibre with very narrow lumen; *B*, wood fibre with larger lumen and showing oblique, slit-like simple pits (*s. p.*); *C*, end of wood fibre showing saw edge; *C′*, end of wood fibre showing forked structure; *D*, ends of two tracheids from *Pinus* showing numerous bordered pits (*b. p.*); *E*, Tracheid from *Quercus; F*, wood-parenchyma strand, showing individual cells and simple pits (*s. p.*); *G*, chambered wood-parenchyma strand from *Juglans*, showing crystals of calcium oxalate; *H*, conjugate parenchyma cells; *K*, portion of a vessel segment showing simple perforation (*p*); *L*, portion of a vessel segment showing scalariform perforation (*Sc. p.*). Greatly enlarged.

Robinia (Plate III, Fig. 3) and *Toxylon* they are in rather large, compact masses in the late wood, separated by groups or bands of pores and parenchyma. In any wood in which they occur they are most abundant in the median portion of the growth ring, and material decrease in the width of a ring is usually at their expense.

The ends of most wood fibres are smooth and uniformly

tapering, but sometimes they are flattened, or forked, or with a saw edge (Fig. 2, *C*, *C′*), adding to the toughness of the wood. Fibres usually run parallel to one another, but in some woods they exhibit a decided interweaving which produces an irregularly grained wood very difficult to split.

TABLE II

LENGTH OF WOOD FIBRES IN DICOTYLEDONOUS WOODS

BOTANICAL NAME	Average mm.	Maximum mm.	Minimum mm.
Acer rubrum	.75	1.00	.50
Betula nigra	1.80	2.20	1.50
Castanea dentata	1.15	1.45	.80
Celtis occidentalis	1.25	1.70	1.05
Fagus americana	1.20	1.70	.75
Hicoria alba	1.35	1.70	.90
Ilex opaca	1.45	2.00	1.15
Juglans nigra	1.10	1.65	.65
Liquidambar styraciflua	1.60	2.00	1.25
Liriodendron tulipifera	1.90	2.50	1.40
Magnolia acuminata	1.75	2.30	1.00
Nyssa sylvatica	1.70	2.35	1.05
Platanus occidentalis	1.90	2.30	1.30
Populus deltoides	1.40	2.20	.50
" grandidentata	1.00	1.35	.65
" heterophylla	1.35	1.80	1.00
" trichocarpa	1.15	1.90	.50
Quercus alba	1.25	1.50	1.00
" coccinea	1.50	2.10	1.00
" michauxii	1.55	1.80	1.10
" rubra	1.20	1.45	.70
" virginiana	1.40	1.80	.85
Salix nigra	.85	.95	.45
Tilia americana	1.15	1.45	.85
Ulmus americana	1.50	1.90	1.15

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WOOD PARENCHYMA

Parenchyma occurs in the secondary xylem of all woody plants, and, with few exceptions, is disposed in two systems: (1) the vertical, composed of more or less scattered rows of cells forming the *wood parenchyma;* and (2) the horizontal, made up of plates of cells extending radially and at right angles to the axis — the *medullary rays* or *pith rays.* Its chief function is the distribution and storage of elaborated food materials.

Typical wood-parenchyma strands (Fig. 2, *F;* Plate IV, Figs. 5, 6) of Dicotyledons resemble septate wood fibres, but have (1) thinner walls, (2) simple, rounded or lenticular pits instead of oblique, slit-like simple or bordered pits, and (3) cross walls equal in thickness to the lateral walls. The individual cells of a wood-parenchyma strand are mostly short and prismatic, pitted with simple pits and (with the exception of the terminal ones, which are pointed) with transverse or oblique end walls. Between wood fibres and wood-parenchyma strands are intermediate forms without septa — *substitute fibres* or *intermediate wood fibres.*

Where wood parenchyma borders on large vessels it is usually much flattened as a result of the pressure of the expanding vessel segments. In such locations also are sometimes special forms termed *conjugate cells* because of flatly tubular processes extending from one to another slightly distant, thus uniting them (Fig. 2, *H*).

There are special forms of wood parenchyma in which the individual cells are divided by cross walls into small chambers of approximately even size which contain solitary crystals, usually of calcium oxalate (Fig. 2, *G;* Plate IV, Fig. 6). Such crystals are only slightly soluble even in the strongest acids, and are very plainly visible under high magnification in both cross and longitudinal sections. Crystals occur in all species of *Quercus,* though they are commonly more abundant in the live oaks than in deciduous species. In *Juglans* (Plate IV, Fig. 6), *Hicoria* (Plate IV, Fig. 3), and *Diospyros,* crystals are often quite conspicuous. Calcium-oxalate crystals are also common in ray-parenchyma cells.

The distribution and arrangement of wood-parenchyma strands in different species are subject to considerable variation. As seen on cross sections of woody Dicotyledons the cells may be (*a*) scattered irregularly throughout the growth ring (Plate V, Figs. 3, 5), (*b*) arranged in tangential lines or bands (Frontispiece,

Plate IV, Figs. 1, 2), (*c*) terminal, *i.e.*, comprising the outer limit of the growth ring (Plate III, Fig. 6; Plate V, Fig. 2; Plate VI, Fig. 2), (*d*) surrounding pores (Plate III, Figs. 3, 5), (*e*) arranged in radial rows. These features are quite important in classifying woods. For example, in *Fraxinus americana* the pores in the late wood are usually joined tangentially by narrow bands of wood parenchyma, while in *F. nigra* (Plate V, Fig. 2) the pores are rarely so united. In *Hicoria* (Plate IV, Fig. 1) wood parenchyma is in numerous, fine, concentric lines as distinct as the rays, while in *Diospyros* (Plate IV, Fig. 2) the lines are finer than the rays and very indistinct. In *Tilia* wood parenchyma is in tangential lines, but is not so disposed in *Liriodendron*, *Magnolia*, and *Æsculus*. In *Liriodendron* (Plate VI, Fig. 2) and *Magnolia* the outer limit of the growth ring consists of 2–4 rows of tangentially flattened wood-parenchyma cells with very thick, copiously pitted radial walls.

Wood parenchyma is present in the wood of all Gymnosperms except the *Taxaceæ*. The cells are invariably associated with resin formation and are usually referred to as *resin cells* or *epithelial cells*, according as they are more or less scattered or surrounding resin ducts.

Resin cells are usually cylindrical or prismatic, thin-walled, with transverse terminations more or less strongly marked with simple pits. The pits in the side walls are often few and invariably simple. Resin cells can usually be distinguished on cross sections under the microscope by their thin walls, simple pits, or better by the deep color of their contents. If the section passes near enough to an end wall the simple pits therein give the appearance of a sieve plate (Fig. 10). While in most cases resin cells are invisible without the microscope, and often not readily found with it, yet in *Juniperus*, *Taxodium*, and *Sequoia* they are usually conspicuous, not infrequently giving rise in the first two species to wavy tangential lines in the growth ring, visible to the unaided eye.

The distribution of the resin cells is variable. In some cases (*e.g.*, *Thuya*) they are scattering; in others (*e.g.*, *Taxodium* [Plate II, Fig. 1], *Juniperus* [Plate II, Figs. 3, 4], *Libocedrus*) they are disposed in well-defined zones concentric with the growth ring, being most abundant as a rule in the transition zone between early and late wood. In still other cases (*e.g.*, *Tsuga*) there is often a tendency of some of the resin cells to aggregation, and in

some cases the formation of imperfect resin ducts or resin cysts (Fig. 10). (See RESIN DUCTS.)

In *Pinus* (Fig. 8) wood parenchyma is found only in association with resin ducts, isolated resin cells being absent; while in *Larix* and *Pseudotsuga* resin cells are occasionally found on the extreme outer face of the late wood. In *Abies* resin cells are remote and inconspicuous; in *Thuya plicata* they are present, though often zonate in widely separated growth rings, thus often apparently absent. In *Sequoia* (particularly *S. sempervirens*) the resin cells are partially filled with dark resin masses which appear on longitudinal surface as fine dotted lines, or under lens as rows of black or amber beads.

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RAYS

Medullary or pith rays, for brevity termed simply *rays*, appear on the cross section of a stem as radial lines crossing the growth rings at right angles and extending into the bark (Fig. 1). A few of them originate at the pith and are commonly known as *primary rays*. Successively, as the stem increases in size, additional or *secondary rays* arise between those already formed. A ray may arise in the cambium layer at any point, and once formed its growth is continuous.*

Under the microscope the line formed by the ray becomes a radial series of mostly elongated cells usually with transverse end walls (Plates II–IV). Viewed radially a ray appears as a muriform structure composed of from one to many tiers of brick-shaped cells (Plate IV, Figs. 5, 6). In tangential section the ends of the rays are visible, showing to advantage their height, shape,

* When on cross or radial sections a ray appears to be discontinuous, it is probable that it has merely been missed by the plane of section. This emphasizes the importance of making cross sections exactly at right angles to the axis of growth, and radial sections as nearly as possible parallel with the rays.

width, and distribution, and also the outline in cross section of the component cells (Plate III, Fig. 1; Plate IV, Figs, 3, 4; Plate VI, Figs. 3, 4, 6).

Ray cells are usually elongated in the radial direction. This is normally the case in Gymnosperms and usually so in the woody Dicotyledons. Not infrequently in the latter, however, part or all of the cells are *upright, i.e.*, with their greatest diameter vertical, or are square. The marginal cells are sometimes upright and the interior cells radially elongated or *procumbent* (Fig. 3). The upright cells are often very irregular, especially the outermost marginal rows; sometimes they are nearly square; again they are in palisade arrangement. When these upright or square cells are in

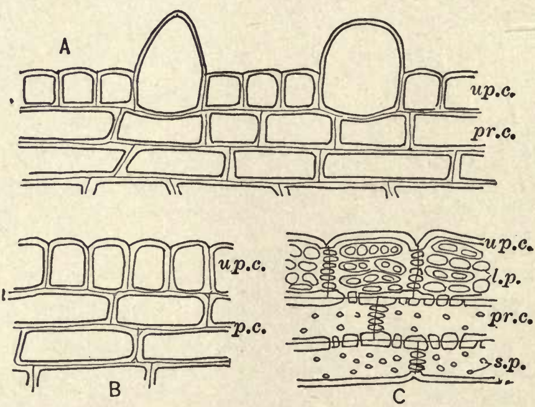

FIG. 3.—Radial sections of heterogeneous rays. *A*, *Sassafras sassafras* (sassafras); *B*, *Nyssa sylvatica* (black gum); *C*, *Æsculus octandra* (buckeye), showing large pits (*l. p.*) in upright cells (*up. c.*), where they adjoin vessels; and small pits (*s. p.*), in procumbent cells (*pr. c.*). No pits are shown in *A* and *B*. Magnified about 150 diameters.

contact with large vessels the separating walls are characteristically marked with very large pits whose polygonal or oval outlines present the appearance of lattice work (Fig. 3, *C*). The lateral walls of similarly located procumbent cells usually contain few small pits. Moreover, in proximity to large vessels the walls between all ray cells are usually thicker and much more abundantly pitted than elsewhere. Upright cells are not always easy to distinguish from the cells of wood-parenchyma fibres, especially where they cross the latter, on account of the similar direction of their longitudinal diameters.

Rays consisting wholly of procumbent cells may be said to be *homogeneous;* those which contain both upright and procumbent cells, *heterogeneous* (Fig. 3). Heterogeneous rays are characteristic of many dicotyledonous woods, and are features of importance in classification. For example, *Celtis* has heterogeneous rays, while those of *Ulmus* are homogeneous. The same distinction obtains between *Salix* and *Populus, Sassafras* and *Fraxinus.* The rays of *Sassafras* are peculiar in having a few of the marginal cells abnormally large and rounded or ovate (Fig. 3, *A*).

The rays in the wood of Gymnosperms are for the most part one cell wide, *i.e.*, uniseriate, and from 1 to 20 cells high. It is not

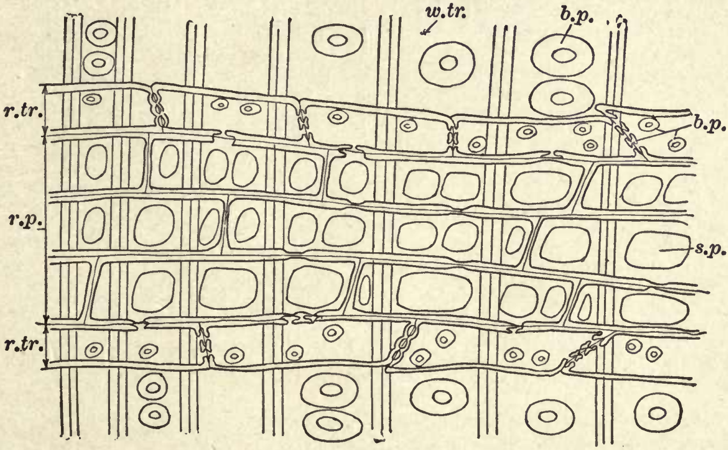

FIG. 4.—Radial section of ray of *Pinus strobus* (white pine); showing the smooth upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*) of large simple pits (*s. p.*), communicating with the wood tracheids (*w. tr.*) adjacent; *b. p.*, bordered pits. Magnified about 250 diameters.

uncommon to find biseriate rays, and those which contain resin ducts (*Pinus, Picea, Larix, Pseudotsuga*) are multiseriate. The latter, because of their shape as seen on tangential section, are called *fusiform rays* (Fig. 9).

In woody Dicotyledons there is more variation in the rays. In some instances (*e.g.*, *Æsculus* [Plate VI, Fig. 6], *Salix, Populus*) low uniseriate rays only are present. At the other extreme is *Quercus* (Plate III, Fig. 1), where the largest rays are from 25 to

75 cells wide and several hundred high. These large rays give rise to the handsome figure of quarter-sawed (*i.e.*, radially cut) oak lumber. Besides the large rays in *Quercus* there are numerous intermediate ones, mostly uniseriate and 1–20 cells high (Plate III, Fig. 1). In *Platanus* the rays are uniformly broad (10–15 cells), while in *Fagus* only a portion of the rays are broad (15–25 cells), the intermediate ones being uniseriate. In some of the evergreen oaks, *Carpinus* and species of *Alnus* (Plate V, Figs. 3, 4), the large rays appear to be composed of numerous small ones

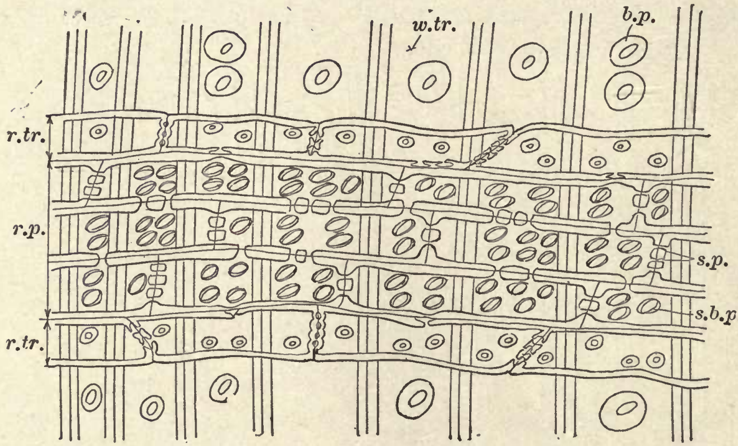

Fig. 5.—Radial section of a ray of *Pinus edulis* (piñon pine), showing the smooth upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*) of small semi-bordered pits (*s. b. p.*), communicating with the wood tracheids (*w. tr.*) adjacent; *s. p.*, simple pit; *b. p.*, bordered pit. Magnified about 250 diameters.

separated by wood fibres. Such rays are termed *aggregate* or *compound* rays; sometimes also *false rays.* Every ray, regardless of its width at the middle, tapers to an edge so that the upper and lower margins are a single cell wide.*

The comparative distinctness which rays on cross section present to the unaided eye is important in separating certain woods which bear superficial resemblance. For instance, the

* For this reason cross sections often do not afford a correct idea of ray width.

rays in *Sassafras* are much more distinct than in *Fraxinus;* likewise in *Celtis* and *Ulmus, Tilia* and *Æsculus, Acer* and *Betula.* In white oaks the height of the large rays averages considerably greater than in the red or live oaks.

In dicotyledonous species the rays are composed wholly of parenchyma. In certain Gymnosperms (*Pinus, Larix, Picea, Pseudotsuga, Tsuga,* and occasionally in others) ray tracheids are present (Figs. 4–7). They are usually marginal, but often interspersed and sometimes they compose entire rays, particularly

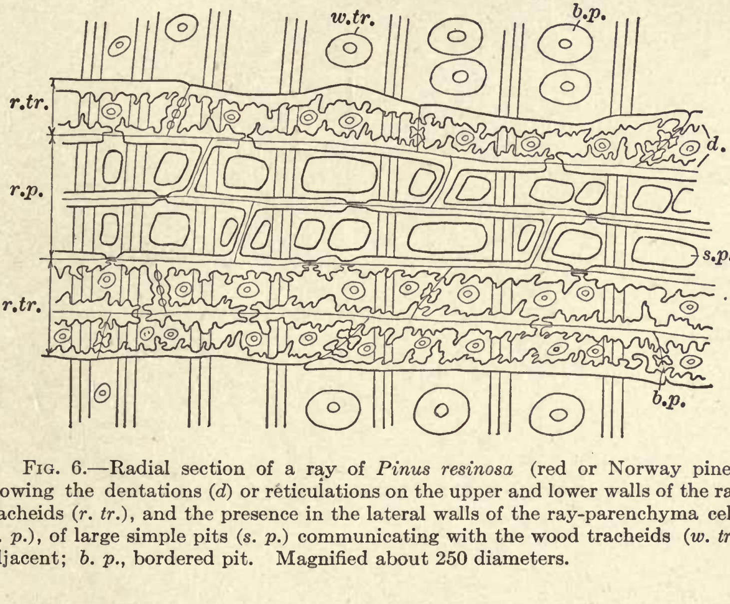

FIG. 6.—Radial section of a ray of *Pinus resinosa* (red or Norway pine), showing the dentations (*d*) or reticulations on the upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*), of large simple pits (*s. p.*) communicating with the wood tracheids (*w. tr.*) adjacent; *b. p.*, bordered pit. Magnified about 250 diameters.

low ones. They can be distinguished from the ray-parenchyma cells by the presence of bordered pits in the lateral and especially the end walls. They are often irregular in outline and are devoid of visible contents. They have their counterparts in the parenchymatous tracheids surrounding the epithelial cells of resin cysts and ducts. In the young root, and sometimes in the young stem as well, special upright or oblique forms occur which may be considered as transitional from wood tracheids to ray tracheids.

The character of the upper and lower walls of the ray tracheids, whether smooth, as in soft pines, or dentate or reticulate, as in

pitch pines, affords a constant diagnostic feature of much importance in separating the two great groups of *Pinus* (Figs. 4–7). Ray-parenchyma cells in general communicate with each other, with the ray tracheids, and with the adjacent wood elements by means of pits always simple in the wall of the parenchyma cell,

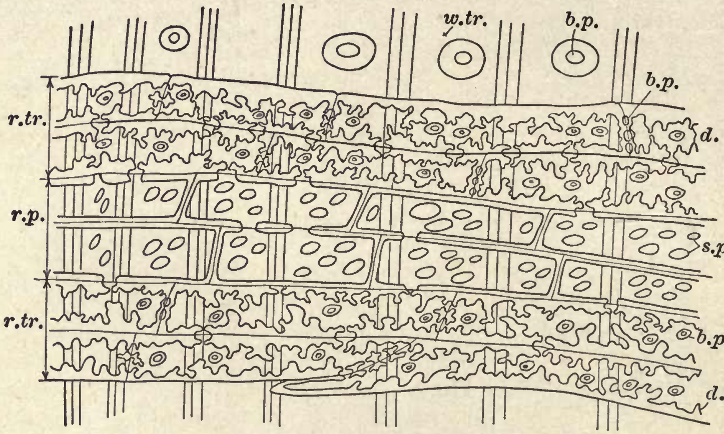

FIG. 7.—Radial section of a ray of *Pinus palustris* (longleaf pine), showing the dentations (*d*) or reticulations on the upper and lower walls of the ray tracheids (*r. tr.*), and the presence in the lateral walls of the ray-parenchyma cells (*r. p.*) of small simple pits (*s. p.*), communicating with the wood tracheids (*w. tr.*) adjacent; *b. p.*, bordered pit. Magnified about 250 diameters.

but commonly more or less bordered in the other. Often certain cells of a ray have thicker walls and more numerous pits than the others.

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RESIN DUCTS

Resin ducts are long, narrow, intercellular channels surrounded by parenchyma cells and filled with resin (Fig. 8). Unlike vessels, they have no walls of their own, but are limited by a layer of cells called *epithelium.* The epithelial cells are thin-walled in *Pinus* and mostly thick-walled in *Larix, Picea,* and *Pseudotsuga.* When thick-walled the cells are rounded and show clearly in cross section, while those with thin walls are compressed and very likely to be torn in sectioning.

Resin cysts are very short, duct-like, intercellular spaces very common in *Sequoia, Tsuga,* and *Abies.* Not infrequently they are in longitudinal series, but differ from a true duct in having numerous constrictions.

Resin ducts are largest and most abundant in *Pinus,* where they are fairly well distributed throughout the growth ring, though usually more numerous in the transition zone between early and late wood. They are comparatively large in most species, averaging about 0.25 mm., and are readily visible to the unaided eye. On longitudinal surface they appear as long, delicate lines like pin scratches, filled with resin. In *Larix, Picea,* and *Pseudotsuga* the ducts are smaller, sometimes invisible without lens, fewer in number, and irregularly distributed, often more or less grouped.

In addition to the ducts extending in a vertical direction, there are horizontal ducts in the *fusiform rays* (Fig. 9). The two series are united at infrequent intervals.

Resin ducts very commonly develop as a result of injury, not only in genera in which they occur normally, but also in others

(*e.g.*, *Tsuga, Abies, Sequoia*) where normally absent. The formation of these *traumatic resin ducts,* as they are called, following wounding by chipping of the outer layers of the sapwood of *Pinus palustris,* is the source of most of our turpentine and other naval stores. Traumatic ducts can be distinguished from normal ones

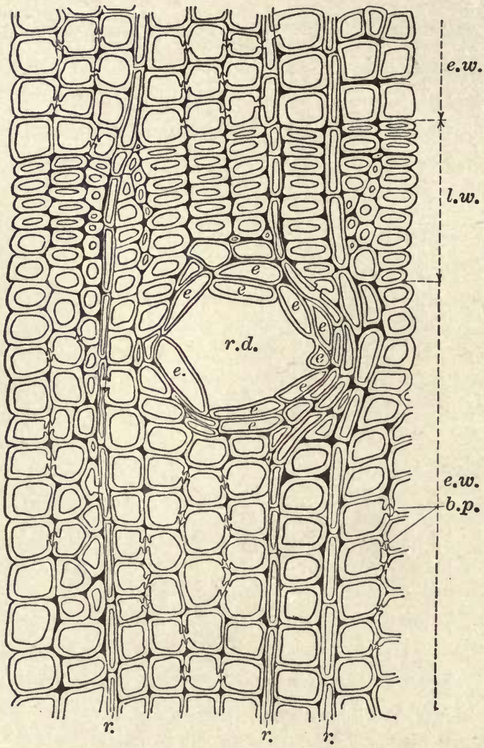

Fig. 8.—Cross section through a portion of two growth rings of *Pinus ponderosa* (western yellow pine); *r. d.*, resin duct; *e.*, epithelial cells; *r.*, ray; *e. w.*, early wood; *l. w.*, late wood; *b. p.*, bordered pit. Magnified about 200 diameters.

by their peculiar localization, usually, as seen on cross section, forming one or more compact rows concentric with the growth ring (Fig. 10).

Gum ducts occur sporadically in the woods of certain indigenous Dicotyledons, viz., *Liquidambar, Swietenia* and *Prunus.*

In *Leitneria floridana* numerous resin ducts are found at the margin of the pith, but are not in the wood. The epithelial cells are thick-walled and in a single layer.

Resin ducts are features of great systematic importance. Their presence in *Pinus*, *Picea*, *Larix*, and *Pseudotsuga* serves as an adequate basis for separating the woods of these four genera from other Gymnosperms. Their relative size, distribution, and occurrence, and the character of the epithelium, whether thick or thin-walled, are features made use of in specific diagnoses.

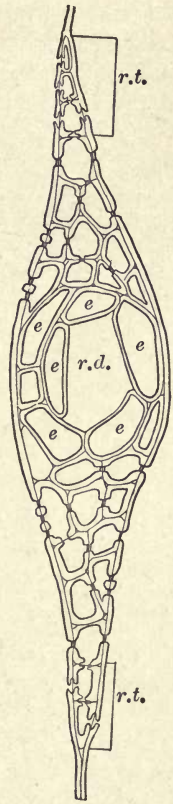

FIG. 9.—Tangential section of a fusiform ray from *Pinus ponderosa* (western yellow pine); *r. d.*, horizontal resin duct; *e.*, epithelial cells; *r. t.*, ray tracheids; the remainder of the cells are ray-parenchyma cells. Magnified about 200 diameters.

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PITS

All wood elements when first formed are limited by a very thin cellulose membrane, the *primary wall.* Subsequent development involves an internal thickening which is composed very largely of lignin, the *secondary wall.* This thickening may proceed uniformly, or, as is usually the case, small gaps, called *pits*, occur. A pit is merely an unthickened portion of the cell wall. Pits are of two principal types, *simple* and *bordered* (Fig. 11).

Intermediate forms exist whose reference to either group is arbitrary.

A simple pit is one in which the thickening about a spot on the primary wall forms a *canal* which is equally wide throughout its length, or narrowing outward (Fig. 11, *H*). The length of the canal is determined by the thickness of the secondary wall. When simple pits occur in very thick-walled cells, there is often a tendency to a slight funnel-formed enlargement of the canal toward

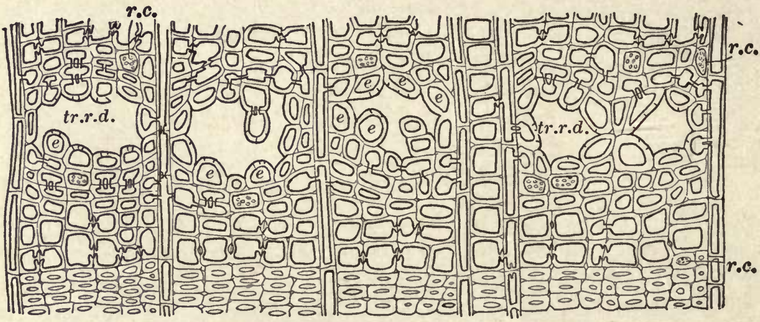

FIG. 10.—Cross section of a wound area in *Tsuga canadensis* (eastern hemlock) showing five traumatic resin ducts (*tr. r. d.*), in tangential row. Note thick-walled epithelial cells (*e*), and occasional resin cells (*r. c.*), showing sieve-like end walls. Magnified about 150 diameters.

the primary wall. Often the canal widens sufficiently to present the appearance of a narrow border (Fig. 11, *G*). Seen in profile, as in section, the pit canal of such a pit is narrow at the end toward the centre of the cell, but widens gradually outward.

A bordered pit is one in which the canal widens suddenly, that is, with a distinct angle, toward the primary wall (Fig. 11, *A*). In surface view a bordered pit appears as a bright spot or slit within a circle or ellipse (Fig. 11, *B*). This outer circle marks the limit of the unthickened area; the bright spot is the inner opening or *aperture* of the canal; the zone between the two is called the *border*.

Pits, especially bordered ones, usually are paired on opposite sides of the primary-cell walls. Pits between vascular elements are invariably bordered; between parenchymatous elements, invariably simple; between vascular and parenchymatous, they may be simple, but more frequently are *semi-bordered*, that is,

bordered in the vessel or tracheid, and simple in the adjacent parenchyma cells (Fig. 11, *F*). Pits in typical wood fibres are simple and slit-like, and usually in oblique position (Figs. 11, *K*; 2, *B*). In many cases, however, where the fibres resemble tracheids their pits are more or less bordered. The fibres of the bast have only simple pits.

The shape of the border is commonly circular, but may be oval, lenticular, oblong, or, in the case of dense aggregation, polygonal. *Scalariform markings* found on the vessel walls in certain

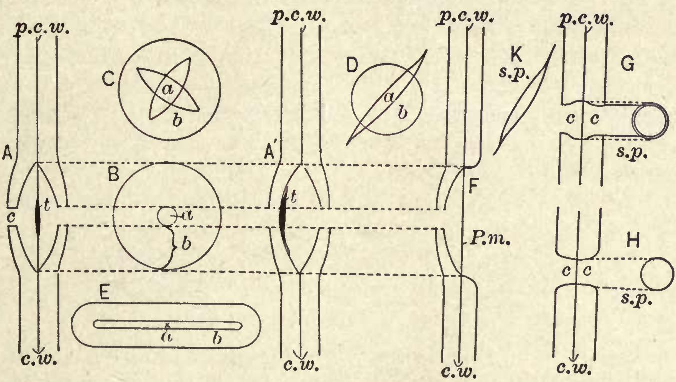

FIG. 11.—Schematic representation of pits, greatly enlarged. *A*, section of bordered pit showing cell walls (*c. w.*), primary cell wall (*p. c. w.*), pit canal (*c*), torus (*t*); *A'*, the same with torus (*t*) shoved to one side and lying lid-like against the aperture of the pit canal; *B*, surface view of bordered pit shown in *A* or *A'*, showing aperture (*a*) and border (*b*); *C*, surface view of bordered pit with lenticular aperture (*a*), the crossed appearance being due to the fact that the apertures on opposite sides of the pit are shown; *D*, surface view of a bordered pit with slit-like aperture (*a*), common in thick-walled tracheids of late wood in gymnospermous woods; *E*, surface view of scalariform bordered pit with narrow, elongated aperture (*a*) and border (*b*); *F*, section of a semi-bordered pit showing border on one side only; *G*, simple pit with funnel-formed canal and appearing slightly bordered in surface view; *H*, ordinary simple pit with canal (*c*) uniform or narrowing outward (*i.e.*, toward primary cell wall); *K*, surface view of slit-like pit common in wood fibres.

woods (*i.e.*, *Magnolia* [Plate VI, Fig. 3], *Hamamelis* and *Liquidambar* in part) are merely much-elongated bordered pits which appear as horizontal clefts with only narrow portions of the wall between them (Fig. 11, *E*).

The pit cavities of two adjacent pits are separated by the primary wall which persists as a *limiting membrane* (Fig. 11, *p.m.*).

This membrane, which is really made up of two membranes of contiguous cells which have become united in development, is very thin toward the border of the pit, but usually thickened near the centre. This thickened portion is called the *torus* (Fig. 11, *t*). The pit membrane very frequently increases in size and bulges out so that the torus lies lid-like against the aperture of the pit canal (Fig. 11, *A'*). A sieve-like structure of the pit membranes has been observed in the bordered pits of the vessels in certain species.*

Between the bordered pits on the radial walls of the tracheids of Gymnosperms it is very common to find folds of cellulose, which, when properly stained, are quite conspicuous under the compound microscope. These folds, which appear as horizontal or more or less semi-circular markings, sometimes doubled, are most abundant in the thin-walled tracheids of the early wood. They are without diagnostic value.

The apparent function of pits is to facilitate the passage of some part of the cell contents from one cell to another. Bordered pits are mostly associated with water transfer, and simple pits with the distribution of elaborated food.

Pits are of considerable value for systematic purposes. For example, in the white pines and *Pinus resinosa*, the radial wall of each ray-parenchyma cell shows one or two large simple pits communicating with each adjacent wood tracheid, while in the foxtail and nut pines and in the hard pines there are three to six rather small pits so communicating (Figs. 4–7). The presence of pits in the tangential walls of the tracheids of the late wood in soft pines, and their absence in similar location in the pitch pines, serve as an additional point of distinction between these two great groups.

While the pits in the radial walls of the tracheids of Gymnosperms are usually in a single row, they may occur in biseriate or triseriate arrangement. In the larger tracheids of *Tsuga* they are mostly biseriate. In *Taxodium distichum* they are characteristically crowded, flattened, and often irregularly arranged.

In dicotyledonous woods as a whole, pits are much smaller and less regular in their distribution than in Gymnosperms. The

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* Jönsson, Bengt.: Siebähnliche Poren in den trachealen Xylemelementen der Phanerogamen, hauptsächlich der Leguminosen, Berichte d. deutschen Botanischen Gesellschaft, Vol. X, 1892, pp. 494–513.

nature of the pits, whether simple or distinctly bordered, in the walls of the wood fibres, and the character of pitting where vessels are in contact with wood parenchyma or the rays, are often helpful in classification. Scalariform bordered pits in the walls of the vessels of *Magnolia* (Plate VI, Fig. 3) serve to distinguish this genus from *Liriodendron* (Plate VI, Fig. 4), in which they are absent or very sparingly developed.

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TYLOSES

It is not uncommon to find the vessels of many Dicotyledons (Plate III, Figs. 3, 4) and the resin ducts of certain Gymnosperms more or less completely filled with pith-like cells called *tyloses.* Usually the walls of the tyloses are very thin, but exceptions occur (*e.g.*, *Robinia* and *Toxylon*) where they may be considerably thickened, sometimes becoming sclerotic. Tyloses in large vessels are plainly visible to the unaided eye, their high lustre giving them the appearance of froth.

Tyloses are cells which have developed from protrusions of the wood or ray parenchyma into the lumen of a vessel or the canal of a duct or an intercellular space. Their formation is apparently due to differences in pressure within the parenchyma cells and the vessels or ducts they adjoin. After vessels lose their sap they are no longer turgid, in fact the air within them becomes rarefied. In consequence of this reduction of pressure the neighboring parenchyma cells rupture or disorganize the limiting membranes of the pits, thereby rendering the lumen of the vessel available for their further extension and development. This explains why tyloses do not occur in vessels which are in a state of activity, but as a

general rule arise in the inner region of the sapwood, *i.e.*, in the wood where the vessels are losing their power of conduction. Once inside the vessel, the intruding cells rapidly divide and grow until the space is filled or their food-supply is exhausted, and thus form a parenchymatous tissue in which carbohydrates may be stored.

The effect of the formation of tyloses is to block up the vessels and render the heartwood impervious, or nearly so, to the entrance of fluids. Tyloses are especially abundant in the vessels of white oaks (*Frontispiece*), thus adding to the technical value of the wood for cooperage. This feature is also of some value in separating the white from the black oaks, since in the latter group tyloses are rather scarce or wanting (Plate II, Fig. 6). In *Quercus marilandica*, however, tyloses are abundant.

Tyloses also occur occasionally in the tracheids of the wood of Gymnosperms, particularly in the wood of the roots. Tyloses in resin ducts are characteristic of *Pinus* and (in less degree) *Picea*, but are sparingly developed or absent in *Larix* and *Pseudotsuga*.

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PITH FLECKS OR MEDULLARY SPOTS

Pith flecks or *medullary spots* are small, brown or grayish, half-moon-shaped patches appearing so commonly on the cross sections of many diffuse-porous woods, especially of the four families *Salicaceæ*, *Betulaceæ*, *Rosaceæ*, and *Aceraceæ*. On longi-

tudinal sections of a stem the pith flecks appear as flattened strands running up and down the stem, and often into the root. Examined microscopically, pith flecks are seen to be made up of irregularly shaped, polyhedral, parenchymatous cells with thick, dark-colored walls copiously pitted with simple pits. At certain seasons the cells are filled with starch grains.

Pith flecks have a pathological origin. They are due to the work of cambium miners whose tunnels are filled by the tylosal development of adjacent uninjured parenchyma cells, especially of the cortex. The dissolved cell fragments and larval excrement are pressed into a narrow border by the rapid growth and division of the "filling cells."

This feature has frequently been used for purposes of classification, principally because of the failure to understand its exact nature. It has been noted in a large number of woods, but is by no means constant in its occurrence. Some stems, for example, contain numerous pith flecks, while other individuals of the same species in the vicinity, or even from the same root stock, do not show them. Furthermore, in stems with pith flecks certain growth rings may be free of them, while others of the same section are thickly dotted, or the lower portion of the stem may contain them and the upper be entirely free.

Taken in connection with other features, however, the presence of pith flecks in abundance may serve to indicate the species. For example, they are usually very numerous in *Betula populifolia* and *B. papyrifera*, and infrequent in *B. lenta*, *B. lutea*, and *B. nigra*, numerous in *Acer rubrum* and *A. saccharinum*, but usually wanting in *A. saccharum*.

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TRABECULÆ: SANIO'S BEAMS

In radial and cross sections of the wood of all Gymnosperms it is not uncommon to find small bars stretched across the lumina of the tracheids from one tangential wall to another. Occasionally they appear in isolated tracheids, but usually traverse in the same direction the entire length of a long radial series (Fig. 12). While the most common form of bar is a simple cylinder slightly enlarged at the points of contact with the cell wall, they may occur as

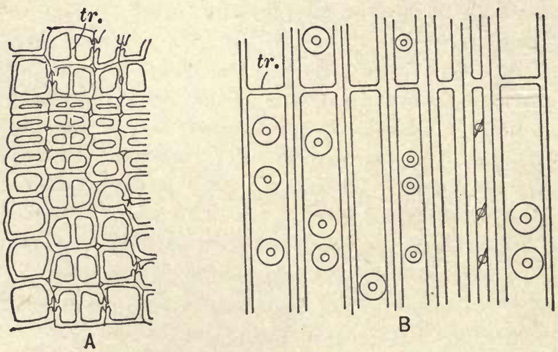

FIG. 12. — Trabeculæ in *Pinus murrayana* (lodgepole pine). *A*, cross section showing tracheids with beams (*tr.*) crossing the middle row in tangential series; *B*, radial section showing beams (*tr.*) which become wider in late wood. Magnified about 150 diameters.

double bars or as constricted plates. These bars, which were first described by Sanio (*loc. cit.*), originate in the cambium and result from the partial resorption of folds in the cell wall. Their function is unknown. Owing to their general distribution throughout all species of Gymnosperms they are without taxonomic value.

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"RIPPLE MARKS"

There are numerous woods which present on longitudinal section (particularly the tangential) fine, delicate cross lines or stripes sometimes called "ripple marks." The distance between these markings varies from 0.11 to 0.50 mm., and is fairly constant for a species. On some woods (*e.g.*, *Æsculus octandra*, *Swietenia mahagoni*, and *Diospyros virginiana* [Plate IV, Figs. 4, 5]), these lines are very clear and distinct to the unaided eye; on others (*e.g.*, *Tilia americana*, *T. pubescens*, and *T. heterophylla*) they are near the limit of vision, or again, they are invisible without the lens. In most species showing these markings the feature is constant and of considerable importance for diagnostic purposes, though in a few species (*e.g.*, *Swietenia mahagoni*) the same piece of wood may show the markings in one place and not in another.

This cross-striping of a wood is due (1) to the arrangement of the rays in horizontal series, or (2) to the tier-like ranking of the wood fibres, vessel segments, or other elements, or (3) to a combination of (1) and (2) (Plate IV, Figs. 4, 5). The lines resulting from the horizontal seriation of the rays is usually more conspicuous and of more common occurrence than those in (2). In the combination of the two forms, which is very common, the junction of the vessel segments or of the fibres is usually between the rays (Plate IV, Fig. 5).

This peculiar arrangement of wood elements is also evidenced on cross section. Where the rays are in perfect horizontal seriation a section between two tiers shows an entire absence of rays. In most instances, however, it results in gaps of irregular width, depending upon the regularity of the stories. Where the rays are much wider near the middle than at the margin, their apparent width when viewed transversely will show considerable variation, according to the relative location of the plane of section. Where the fibres are arranged in tiers, their apparent size is affected in a similar manner.

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GROWTH RINGS

A tree increases in diameter by the formation between the old wood and the inner bark of new woody layers which envelop the entire stem and living branches. In cross section, as on the end of a log, these layers appear as concentric zones or rings (Fig. 1). The distinction between contiguous rings is due to structural peculiarities, augmented in some instances by local deposit of resin or pigment. Each ring consists of two more or less readily distinguishable parts, the inner, called *early wood* (spring wood), and the outer, or *late wood* (summer or autumn wood).

In *ring-porous* woods (*Frontispiece;* Plate III), such as *Quercus, Castanea, Fraxinus,* and *Robinia,* the larger vessels become localized in the early wood, thus forming a region of more or less open and porous tissue, while the wood fibres preponderate in the late wood, thereby producing a much denser layer. In other instances, as in *Acer, Magnolia, Æsculus,* and *Liquidambar* (Plate VI), where the vessels are fairly uniformly distributed—diffuse-porous—the occurrence of growth rings may be due to one or more of the following conditions: (1) a gradual diminution in size of the vessels toward the periphery of the ring; (2) a decided reduction in number of the vessels in the late wood; (3) a change in kind of the wood elements, *e.g.*, where the outer layer of late wood consists wholly or chiefly of wood parenchyma or of tracheids; (4) increase in thickness of the wall of the wood elements near the limit of the late wood.

In Gymnosperms where vessels are wholly absent growth rings are due to variations in the tracheids. Viewed in cross section the cells of early wood are relatively large, thin-walled, and more loosely aggregated; while those of the late wood are smaller, thicker-walled, closely packed together and very often radially flattened, presumably as a result of cortical pressure (Fig. 8; Plate II, Figs. 1, 2, 4). This transition from open to dense structure may be gradual, as in the soft pines, or very abrupt, as in many hard pines. Not infrequently the dense aggregation of cells involves a deepening of the color peculiar to the tissue as a whole. In any wood it is almost invariably the apposition of the more open

early wood to the face of the more compact late wood that serves to define the zones of growth.

The origin of growth rings is physiological. Plants, like animals, seem incapable of indefinitely sustained activity, but require periods of recuperation. In latitudes of decided seasonal changes such periods of rest are provided by the alternation of the seasons, in which case the zones of growth correspond very closely with annual periods. This constancy of relation diminishes towards the equator and, although in the tropics growth rings are not uncommon, they provide no reliable index to the age of the tree. In temperate climates trees occasionally produce *secondary* or *false* rings, usually attributable to some disturbance of the normal course of growth of the season, such as the action of frost, drought, hail, and insect damages. Such rings, however, can usually be distinguished from annual rings by their less pronounced line of demarcation.

Variation in width of different growth rings is common to all trees, and is determined by external conditions of light, heat, moisture, and available food-supply. The cross section of a stem presents in the variable form and size of its rings a history of its growth and nutrition.

The breadth of an individual growth ring may not be uniform all round in consequence of unequal acceleration of the growth on different sides, the ring thus becoming undulating or eccentric. The growth centre is accordingly not coincident with the geometric centre. The more nearly erect the stem and the more nearly perfect the crown, the more closely will the two centres coincide. In some species (*e.g.*, *Carpinus caroliniana* and *Juniperus virginiana*), irregularity of growth causes the trunks to become fluted or even deeply scalloped.

The growth rings near the centre of a stem usually exhibit considerable difference in structure from those later formed. The elements are usually thinner-walled, of shorter length, and less densely aggregated, so that the inner core of wood is comparatively soft and weak. In the wood of Dicotyledons, although the elements characteristic of the species are all present, their characteristic arrangement does not appear clearly until later. This is particularly evident in the distribution of the vessels and wood parenchyma in many woods. Consequently, in the employment of these features for systematic purposes, it is important to use stems of considerable thickness rather than small branches or young shoots.

In ring-porous woods of good growth it is usually the middle portion of the ring in which the thick-walled, strength-giving fibres are most abundant. As the breadth of the ring diminishes, this middle portion is reduced so that very slow growth (fine grain) produces comparatively light, porous wood composed

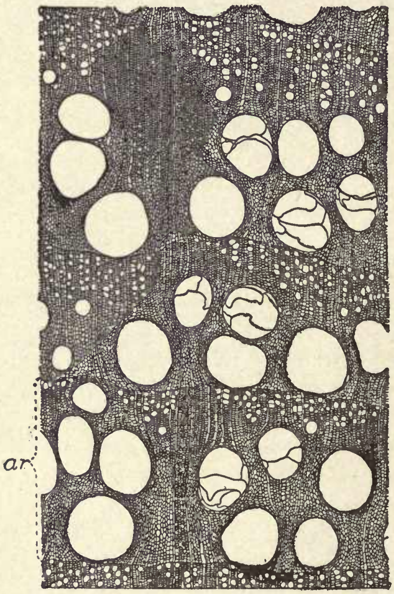

FIG. 13.

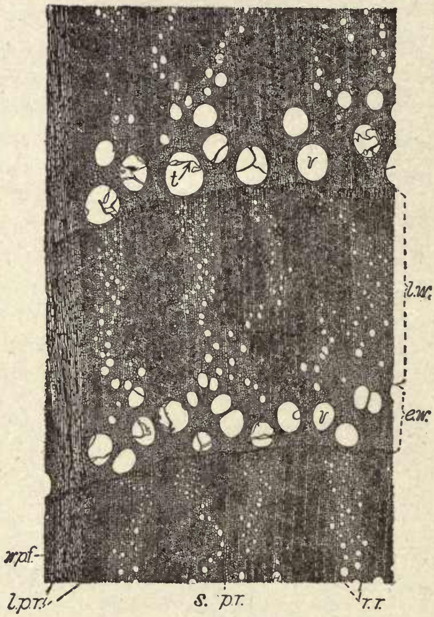

FIG. 14.

FIG. 13.—*Quercus macrocarpa* (bur oak): cross section through three entire growth rings showing very large pores in early wood and general absence of dense-walled wood fibres. Such wood is light, soft, and not strong. Magnified 20 diameters. (From Bul. 102, U. S. Forest Service.)

FIG. 14.—*Quercus macrocarpa* (bur oak): cross section through one entire growth ring and parts of two others, showing comparatively small pores (*v*) in early wood (*e. w.*), and presence of abundant thick-walled wood fibres in the late wood (*l. w.*). Such wood is heavy, hard, and strong. Magnified 20 diameters. (From Bul. 102, U. S. Forest Service.)

mostly of thin-walled vessels and wood parenchyma (Figs. 13, 14). This explains why "second-growth" (*i.e.*, rapidly grown) hickory, ash, and chestnut are stronger than the slowly grown "virgin" stock of the same species. Moreover, in trees of this type there is less early wood formed at the base of a stem than farther up,

because growth begins considerably later at the base. The strongest, densest, and toughest timber is that grown in the open where conditions are favorable to rapid growth.

In diffuse-porous woods, such as *Acer*, *Betula*, *Liriodendron*, and *Fagus*, there seems to be no definite relation between ring width and density. In Gymnosperms, as a rule, wood of medium to fine grain contains a greater proportion of late wood and consequently possesses greater weight and strength than when very fine or very coarse grained.

In this connection the following statement of H. Mayr * is interesting: "Assuming identity of soil, the specific weight and hardness of wood decreases with distance from the optimum climate of its production both toward cooler or warmer climates. It is indifferent whether the annual zones consequently increase or decrease in breadth, or whether the wood is broadleaved or coniferous. Within the natural habitat of any tree the centre of its habitat produces the heaviest and hardest wood."

Various theories have been advanced to explain the formation of early and late wood. Penhallow (following Sachs†) says that the elements of the early wood are "formed under a minimum tension in consequence of which they rapidly attain to relatively great size, and it is therefore found that the first tissue of the season is always most open. In consequence of the great excess of nutrition supplied during this period of growth, and the very rapid process of construction which follows, secondary growth of the walls is limited, and these structures remain thin, while the lumens are correspondingly large."

R. Hartig maintains that the thin-walled early wood is due to poorer nutrition and the necessity of forming conductive tissue, while thick-walled late wood results from better nutriment during the warm and sufficiently moist summer. Wieler, on the other hand, claims that the more unfavorable the conditions of nutrition, the slower the development of assimilating organs, hence the more late wood.

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HEARTWOOD AND SAPWOOD

The course of development of the various wood elements is fundamentally the same, viz., they are formed in the cambium, they increase in size, their walls thicken more or less, they function as living cells for a time, but eventually lose their protoplasmic contents and die. Their change from a living to a dead condition is ordinarily not followed by immediate decay, and the cells continue to perform the mechanical function of support. The parenchyma cells remain alive for a longer time than the other elements.

The outer layers of growth of a tree, especially one of considerable thickness, contain the only living elements of the wood and comprise the *sapwood.* There is usually a sharp line of demarcation between the living elements of the sapwood and the non-living elements of the *heartwood,* though the vigor of the living cells gradually wanes as their distance from the cambium increases. The thickness of sapwood varies widely in different species, in different individuals, in different portions of a single tree, and often on different radii of any particular section. Thin sapwood is characteristic of certain genera, for example *Catalpa, Robinia, Toxylon, Sassafras, Morus, Gymnocladus, Juniperus,* and *Taxus,* while in others such as *Hicoria, Acer, Fraxinus, Celtis,* and *Fagus,* thick sapwood is the rule.

The fact that sapwood occupies the peripheral layers of the stem causes it to form a considerable proportion of the volume. The percentage of sapwood to total volume of the stem is for certain species approximately as follows: *Pinus palustris,* 40;

P. heterophylla, 50; *P. tæda*, 55; *P. strobus*, 30; *Tilia americana*, 65; *Juniperus virginiana*, 25; *Liriodendron tulipifera*, 20; *Quercus alba*, 20; *Robinia pseudacacia*, 12.

In the same species there generally exists a constant relation between the crown space and the cross-sectional area of the sapwood in the stem. Rapidly growing trees and trees in the open have a larger proportion of sapwood than those of the same species growing in less open stands. In the latter case the number of rings in the sapwood is almost always greater.

Heartwood in general is of a darker color than sapwood, due to the presence of gums, resins, and other substances. In some genera, however, there is little difference in appearance between these two portions, for example, in *Nyssa*, *Ilex*, *Celtis*, *Populus*, *Salix*, *Picea*, *Abies*, and *Tsuga*.

Change from sapwood to heartwood is never accompanied by increased lignification. Deposition of large amounts of gum or resin materially increases the weight of the wood, and on that account in certain tropical species the heartwood averages fully one-third heavier than the sapwood.

While physiologically heartwood is that portion of the woody cylinder which does not contain living elements, yet technically only discolored parts are so called, though it of course is without living elements. Branches form heartwood as soon as they cease to grow vigorously, no matter in what part of the crown they are located. In a whorl one branch may be practically all heartwood while none of the others shows any.

Usually heartwood is commercially more valuable than sapwood, partly on account of its color, but more especially because of its greater durability under exposure. In grading lumber sapwood is often considered a defect. Important exceptions are found in the use of paper birch for spools, hickory and ash for handles, spokes, etc., woods for manufacture of pulp, and timber to be impregnated with preservatives, where heartwood is considered undesirable.

The average thickness of the sapwood and the character of the demarcation between heartwood and sapwood are features frequently made use of in classification.

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GRAIN AND TEXTURE

Grain is a general term used in reference to the arrangement or direction of the wood elements and to the relative width of the growth rings. To have specific meaning it is essential that it be qualified. The kinds of grain commonly described are *fine, coarse, even, uneven, rough, smooth, straight, cross, spiral, twisted, wavy, curly, mottled, landscape, bird's-eye, gnarly,* and *silver.*

Coarse grain applies to woods of rapid growth, *i.e.*, it denotes wide rings; *fine grain*, to woods of slow growth. *Even* and *uneven* apply respectively to regularity or irregularity of the growth rings; *rough* and *smooth*, to the manner in which wood works under tools. *Straight grain*, as applied to a tree, occurs when the wood elements are parallel to the axis of growth; as applied to a board, when the radial and tangential planes of structure are parallel to its length. Sawn boards or timbers are often *cross-grained* even when cut from *straight-grained* logs while *straight-grained* pieces may be split from *spiral-grained* trees. The strength of a piece of timber, particularly in bending, rapidly weakens as the plane of its fibres deviates from a direction parallel to its length. On this account split timber is usually stronger than when sawn, a fact made use of in wood-working. For instance, billets for handles and blocks for telegraph-insulator pegs are invariably split.

It is not uncommon in any tree, and usual in many cases, for the wood elements to be arranged spirally about the central axis. The spiral may run to the right or left, but the direction is usually fairly constant within a species. Various theories have been advanced to explain the phenomenon of spiral growth or torsion. The one most commonly accepted considers the obliquity of the fibres a method of accommodating the increase in length of the cells after their formation in the cambium. There seems to be ground for suspecting that wind may have an influence on this spiral development. For instance, trees of *Larix americana* have been observed which, though straight-grained while young, had

developed spirally twisted growth layers after the trees were thirty to forty years old, when, unprotected by associated trees, they were subjected to heavy winds. There is a further possibility that some species have an inherent tendency to develop twisted stems. In any event, when such stems are sawn the lumber is cross-grained and usually unfit for use where strength is required. The extent of the defect depends upon the pitch of the spiral.

When the elements interweave and are not constant in one general direction, wood is also said to be *cross-grained,* though the term *spiral grain* or *interlocked grain* is more applicable. Often this condition does not interfere with tangential splitting. Wood with interlocked fibres is tough and not necessarily weakened, but always tends to warp and twist in seasoning. Examples occur in *Nyssa, Æsculus, Liquidambar,* and *Eucalyptus.*

Wavy grain and *curly grain* result when the fibres undulate but do not cross each other. When the undulations are large the grain is said to be *wavy;* when small, *curly.* Usually the waves are on the radial plane and tangential splitting produces a smooth surface, showing the grain to advantage. Such grain is common in *Acer, Æsculus, Fraxinus, Prunus,* and *Betula.* It is most common near the roots and at the insertion of large branches.

Silver grain is produced by quarter-sawing timber in which the rays are sufficiently high to show readily on radial surface. The appearance of the rays adds very materially to the value of woods for cabinet work and furniture. Species which exhibit conspicuous silver grain are *Quercus* (all species, but particularly *Q. alba*), *Platanus occidentalis, Fagus americana,* and to a less extent *Acer saccharum, Prunus serotina,* and *Swietenia mahagoni.*

Texture is a term which refers to the relative size, quality, or fineness of the elements as affecting the structural properties of a wood. Like *grain,* it requires qualifying adjectives to attain specific meaning. The most common attributes of texture are fineness and coarseness, evenness and unevenness. *Coarse texture* applies to woods with many large elements, or the average size of which is large, for example, *Castanea, Gymnocladus, Sequoia.* In *fine texture* the opposite condition prevails, as in *Juniperus, Æsculus, Salix, Populus.*

Even texture or *uniform texture* are terms used to describe woods whose elements exhibit little variation in size, for example, *Taxodium* (Plate II, Fig. 1), *Juniperus* (Plate II, Figs. 3, 4), *Sequoia, Æsculus* (Plate VI, Fig. 5). *Uneven texture* applies to

the opposite condition, such as is common in all prominently ring-porous woods (Frontispiece; Plate III), (*e.g.*, *Quercus*, *Castanea*, *Ulmus*, *Fraxinus*), and in other woods with decided differences between early and late wood (*e.g.*, *Pinus palustris*, *P. tæda*, and *Pseudotsuga*).

Texture and grain are terms very commonly confused in popular usage. The distinctions as above expressed will obviate the difficulty resulting from the attempt to make the term "grain" too comprehensive.

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KNOTS

Branches originate, as a rule, at the central axis of a stem and, while living, increase in size by the addition from year to year of woody layers which are a continuation of those in the stem. From this it follows that the form of the included portion or *knot* approaches that of a cone with its apex inward.

During the development of a tree most of the limbs, especially the lower ones, die, but persist for a time—often for a great many years. Subsequent layers of growth of the stem are not intimately joined with the fibres of the dead limb, but are laid around its base. Hence dead branches produce *loose knots* which may drop out after the tree has been cut into lumber.

The stubs of dead limbs that have broken off are usually occluded by subsequent growth so that the outer surface of the bole is smooth or clear, especially toward the butt. The interior of all stems is more or less knotty, but in butt logs the knots are fewest and smallest. Sometimes knots enhance the value of timber for cabinet work and interior finish, by giving it a pleasing figure. Material cut near the junction of a large limb or at the base of a crotch usually exhibits very handsome grain.

Knots materially affect checking and warping, ease in working, and cleavability of timber. They are defects which weaken timber and depreciate its value for structural purposes where strength is an important consideration. The weakening effect is much more serious where timber is subjected to bending and tension than where under compression. The extent to which a knot affects the strength of a beam depends upon its position, size, direction

of fibre, and condition. A knot on the upper side is compressed, while one on the lower side is subjected to tension. The knot, especially (as is often the case) if there is a season check in it, offers little resistance to tensile stress. Small knots, however, may be so located in a beam as actually to increase its strength by tending to prevent longitudinal shearing. Knots in a board or plank are least injurious when they extend through it at right angles to its broadest surface. Knots apparently have little effect on the stiffness of timber.

"At the junction of limb and stem the fibers on the upper and lower sides of the limb behave differently. On the lower side they run from the stem into the limb, forming an uninterrupted strand or tissue and a perfect union. On the upper side the fibers bend aside, are not continuous into the limb, and hence the connection is imperfect.

"Owing to the arrangement of the fibers, the cleft made in the splitting never runs into the knot if started on the side above the limb, but is apt to enter the knot if started below, a fact well understood in woodcraft." *

Sound knots are as hard as, and usually considerably harder than, the wood surrounding them. In coniferous woods they are commonly highly resinous, and in finished lumber are apt, on that account, to fail to retain paint or varnish. When such trees decay the knots remain sound and are prized for fuel. In grading lumber and structural timber, knots are classified according to their character (*sound, loose, encased*), size (*pin, standard, large*), and direction of fibre (*round, spike*).

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DENSITY AND WEIGHT

Density of wood varies widely in different species, in different individuals, and even in different portions of the same tree. The specific gravity † of wood substance is about 1.6; hence the

* Roth, *loc. cit.*, p. 23.

† By specific gravity is meant the ratio of the weight of thoroughly dried

reason any wood floats in water is because of the buoyancy of the air imprisoned in its elements and spaces. When this air is displaced by water the wood becomes "waterlogged," and will no longer float. The greater the proportion of cell wall the greater the density; consequently late wood is denser and of higher specific gravity than early wood, and the greater the proportion of late wood the denser the wood as a whole. Woods composed largely of thick-walled, narrow-lumined fibres are always dense and heavy. Other things being equal, the weight of wood is a good criterion of its hardness and strength.

In practice the weight of wood is calculated from small, sound specimens which have been oven-dried at a temperature of 100° C. (the boiling-point of water) until they reach a constant weight. Since weight is subject to wide variations, the single value usually assigned to a species is really the average of a large number of determinations and is applicable only in a general way. If a wood weighs less than thirty pounds per cubic foot it is considered light; if between thirty and forty pounds, medium light or medium heavy; and if more than forty pounds, heavy.

The lightest wood in the United States is that of *Leitneria floridana*, the specific gravity of which is 0.21 for body wood and 0.15 for root wood. The wood of *Condalia ferrea* has a specific gravity of 1.3; that of *Guaiacum sanctum* 1.14. From the investigation of 429 American species, as published in the report of the Tenth Census of the United States, it appears that 242 species, including most of the commercial woods, lie between 0.45 and 0.75 in specific gravity.

TABLE III

One Hundred and Fifty Trees of the United States Arranged in Order of the Average Specific Gravity of Their Dry Woods (Tenth Census).

Species	*Sp. Gr.*	*Species*	*Sp. Gr.*
Condalia ferrea	1.30	Quercus prinoides	.86
Guaiacum sanctum	1.14	Quercus chrysolepis	.85
Quercus virens	.95	Hicoria alba	.84
Quercus texana	.91	Ostrya virginiana	.83

wood to an equal volume of water at its greatest density, which occurs at a temperature of 4° C. (39.2° F.). A cubic foot of pure water at this temperature weighs 62.43 pounds. Dividing the weight in pounds of a cubic foot of wood by 62.43 will give the specific gravity of the wood.

TABLE III—CONTINUED

Species	*Sp. Gr.*
Quercus agrifolia	.83
Hicoria glabra	.82
Cornus florida	.82
Hicoria laciniosa	.81
Quercus michauxii	.80
Hicoria myristicæformis	.80
Pinus serotina	.79
Diospyros virginiana	.79
Toxylon pomiferum	.77
Quercus laurifolia	.77
Prosopis juliflora	.77
Betula lenta	.76
Quercus imbricaria	.75
Pinus heterophylla	.75
Quercus prinus	.75
Ulmus alata	.75
Quercus phellos	.75
Quercus alba	.75
Quercus macrocarpa	.75
Ilex decidua	.74
Hicoria aquatica	.74
Larix occidentalis	.74
Quercus coccinea	.74
Robinia pseudacacia	.73
Quercus nigra	.73
Celtis occidentalis	.73
Carpinus caroliniana	.73
Swietenia mahagoni	.73
Ulmus racemosa	.73
Ulmus crassifolia	.72
Quercus aquatica	.72
Prunus americana	.72
Cratægus crus-galli	.72
Fraxinus quadrangulata	.72
Hicoria olivæformis	.72
Juniperus monosperma	.71
Fraxinus lanceolata	.71
Quercus velutina	.70
Pinus palustris	.70
Ulmus pubescens	.70
Quercus palustris	.69
Gymnocladus dioicus	.69
Acer saccharum	.69
Fagus americana	.69
Gleditsia triacanthos	.67
Betula lutea	.66
Fraxinus americana	.65
Quercus rubra	.65
Ulmus americana	.65
Taxus brevifolia	.64
Pinus edulis	.64
Magnolia grandiflora	.64
Nyssa sylvatica	.64
Taxus floridana	.63
Cupressus macrocarpa	.63
Fraxinus pennsylvanica	.63
Larix americana	.62
Acer rubrum	.62
Juglans nigra	.61
Pinus echinata	.61
Betula papyrifera	.60
Liquidambar styraciflua	.59
Morus rubra	.59
Castanea pumila	.59
Juniperus pachyphlœa	.58
Prunus serotina	.58
Ilex opaca	.58
Juniperus occidentalis	.58
Betula nigra	.58
Betula populifolia	.58
Fraxinus oregona	.57
Platanus occidentalis	.57
Pinus monophylla	.57
Castanopsis chrysophylla	.56
Pinus aristata	.56
Juniperus utahensis	.55
Pyrus americana	.55
Pinus tæda	.54
Pinus balfouriana	.54
Magnolia macrophylla	.53
Pinus inops	.53
Pinus jeffreyi	.53
Pseudotsuga taxifolia	.52
Pinus rigida	.52
Tumion taxifolium	.51
Sassafras sassafras	.50
Magnolia glauca	.50
Æsculus californica	.50
Juniperus virginiana	.49
Pinus resinosa	.49
Alnus oregona	.48
Chamæcyparis nootkatensis	.48
Tumion californicum	.48
Pinus ponderosa	.47

TABLE III—Continued

Species	*Sp. Gr.*	*Species*	*Sp. Gr.*
Abies magnifica	.47	Pinus coulteri	.41
Magnolia acuminata	.47	Pinus murrayana	.41
Populus grandidentata	.46	Populus heterophylla	.41
Chamæcyparis lawsoniana	.46	Juglans cinerea	.41
Picea nigra	.46	Tilia pubescens	.41
Abies nobilis	.46	Picea alba	.41
Taxodium distichum	.45	Populus tremuloides	.40
Æsculus glabra	.45	Libocedrus decurrens	.40
Tilia americana	.45	Asimina triloba	.40
Castanea dentata	.45	Alnus oblongifolia	.40
Catalpa catalpa	.45	Pinus glabra	.39
Salix nigra	.45	Pinus monticola	.39
Pinus flexilis	.44	Pinus strobus	.38
Acer negundo	.43	Abies balsamea	.38
Picea sitchensis	.43	Populus trichocarpa	.38
Æsculus octandra	.43	Thuya plicata	.38
Salix discolor	.43	Pinus lambertiana	.37
Tilia heterophylla	.43	Abies concolor	.36
Tsuga canadensis	.42	Populus balsamifera	.36
Liriodendron tulipifera	.42	Abies grandis	.35
Abies amabilis	.42	Picea engelmanni	.34
Sequoia sempervirens	.42	Thuya occidentalis	.32
Catalpa speciosa	.42	Sequoia washingtoniana	.29
Pinus albicaulis	.42	Leitneria floridana	.21

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WATER CONTENT OF WOOD

Water occurs in living sapwood in three states, viz., (1) in the protoplasmic contents of the cells, (2) in the cell walls, and (3) as free water wholly or partially filling the lumina of cells, fibres, and vessels that have lost their contents. In heartwood water normally exists only in condition (2). In the fresh sapwood of *Pinus strobus*, which may be taken as fairly typical, water comprises about half of the total weight and is distributed approx-

imately as follows: in contents of living cells, 5 per cent; saturating cell walls, 35 per cent; free water, 60 per cent.

In a living tree the wood nearest the bark contains the most water. If no heartwood is present the decrease toward the pith is gradual; otherwise the change is quite abrupt at the sapwood limit. In *Pinus palustris*, for example, the weight of the fresh wood within an inch of the bark may be 50 per cent of water; that between one and two inches, only 35 per cent; that of the heartwood, only 20 per cent. The water content of any particular section of a tree depends upon the amount of sapwood, and is therefore greater for the upper than for the lower portions of the stem; greater for limbs than bole; greatest of all in the roots.

The water content of wood can readily be determined in the following manner: saw off a thin section of wood; weigh carefully on a delicate balance; dry in an oven at a temperature of 100° C. until a constant weight is obtained; reweigh. The difference between the fresh weight and the dry weight is the amount of moisture contained. Computed on a basis of the fresh weight,

$$\text{Per cent of moisture} = \frac{\text{fresh weight} - \text{dry weight}}{\text{fresh weight}} \times 100.$$

Thus if the weight of the original block of wood was twice the final weight, there was as much water as wood; in other words, one-half, or 50 per cent, of the original weight was water. The figures in the preceding paragraph are on this basis.

Computed on a basis of dry weight,

$$\text{Per cent of moisture} = \frac{\text{fresh weight} - \text{dry weight}}{\text{dry weight}} \times 100.$$

In the problem cited above the loss of moisture was 100 per cent of the dry weight. This method furnishes a constant basis for comparison, while the other varies with every change in moisture degree. Subsequent references to the per cent of moisture will refer to computation on the basis of dry weight.

It is impossible to remove absolutely all the water from wood without destroying the wood. Wood is considered thoroughly dried when it ceases to lose weight in a constant temperature of 100° C., though it still retains 2 to 3 per cent of moisture, and if exposed to higher temperature will continue to give up water.

Seasoning, which is essentially drying, adds appreciably to the strength, and, in slightly less proportion, to the stiffness of

wood. A piece of green spruce timber, for example, may become four times stronger when thoroughly dried.* This is an extreme case, however, and does not apply to large timbers where checking, which always occurs to some extent, may counterbalance partially or even entirely the gain in strength due to drying.

In small forms of hardwood material, as implement and carriage stock, and in coniferous timber in some forms, as cross-arms for telegraph poles, thorough and uniform reduction of the moisture content produces a large increase in strength. In fact a comparatively weak wood may, when perfectly dry, be much stronger than a strong wood in a green condition. Consequently tests to determine the mechanical properties of wood must, to be comparable, take into consideration the moisture content of the specimens. By means of a great many tests the relation of the moisture degree to the mechanical properties can be approximated and coefficients or correction factors determined by which the strength value at any given water content can be reduced to a standard (usually 12 per cent) or other desired moisture degree.†

Loss of water from cell lumina alone does not affect the mechanical properties of wood. It is only when the cell walls begin to give up their water that increase in strength, stiffness, hardness, and resilience occur. Conversely, the absorption of water weakens wood only to the point where the cell walls become completely saturated. This critical point has been termed by Tiemann (*loc. cit.*) the *fibre-saturation point.* It varies with different treatments of the wood and under different conditions. The water content at this point is greater in wood previously dried and especially in wood which has been subjected to high temperature than it is in green wood. The amount of moisture at the fibre-saturation point in green wood of various species has been found by Tiemann (*loc. cit.*) to be between 20 and 30 (average about 27) per cent.

The water content of wood materially affects durability. Since decay is produced by fungi, and to a less extent by bacteria, both of which require considerable water for their development,

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* In comparing the strength and stiffness of wood in green and dry conditions, the fact should be borne in mind that, owing to shrinkage, dry wood is more compact and contains a greater amount of wood substance per unit of volume than green wood.

† Such tables have been prepared for several of the commercial woods of the United States. (See Bul. 70 and Cir. 108, U. S. Forest Service.)

all that is necessary to render even the most perishable wood indefinitely immune from decay is to keep it dry. Wood containing not more than 10 per cent of moisture will not decay.

Rate of seasoning differs with the kind of wood and with its shape. A thin piece dries more rapidly than a thicker one; sapwood more rapidly than heartwood; a light, open wood more readily than one that is dense and heavy. Large beams or logs are exceedingly slow in drying, requiring from two to several years' seasoning in the open air before reaching an air-dry condition in the interior. Ties require from three months to a year to season, depending on the kind of timber and the climate. Much depends upon the method of piling, since boards in open piles often dry twice as fast as those in solid piles.

As a result of numerous experiments by the U. S. Forest Service upon large beams of *Pinus palustris* and *P. tæda,* the following conclusions were reached (Bul. 70, p. 123):

"(1) The drying-out process takes place almost wholly through the faces of the beam and not longitudinally, except near the ends.

"(2) The ratio of evaporation through a surface is proportional to the rate of growth or density of the wood near the surface, being most rapid in the case of sapwood.

"(3) If the whole stick is made up of heartwood or the proportion of sapwood is uniform throughout, the longitudinal distribution of moisture is very regular. If the proportion of sapwood is not uniform, on the other hand, the portion containing the most sap is the most susceptible to moisture influences; *i.e.*, it will dry or will absorb moisture the most rapidly.

"The average of two cross-sections of longleaf pine sticks, 12 by 12 inches and 8 by 16 inches and 16 feet long, which were air-dried for two years, showed an average moisture content in the outer portion, cut halfway from surface to centre, of 17.7 per cent, while the inner part contained 25.7 per cent.

"From this it is quite evident that where timber of structural sizes is used, the strength ordinarily reckoned upon should not be greater than that of the green condition."

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SHRINKAGE, WARPING, AND CHECKING

The volume of wood is maximum when the cell walls are saturated with water. When this condition exists the presence or absence of free water in the cell cavities and the intercellular spaces does not affect the volume. When the cell walls begin to dry, they become thinner, but do not contract to an appreciable extent longitudinally. A dry wood cell is therefore of practically the same length as it was in a green or saturated condition, but is smaller in cross section, has thinner walls and a larger lumen. According to Nägeli's hypothesis, the cell wall is composed of aggregations in crystalline form of minute parts or *micellæ*. These *micellæ* are separated by films of water which become thinner as the wall dries and thicker as it swells. This shrinkage is roughly proportional to the thickness of the walls, and in consequence the denser woods or the denser portions of a wood shrink more than those less dense.

Inasmuch as wood is not a homogeneous substance, but an intricate structure composed of cells exhibiting from moderate to extreme variation in shape, size, thickness of walls, and more especially in arrangement, it follows that shrinkage cannot be uniform throughout any specimen. Late wood, being denser, shrinks more than early wood. The ray cells, with their longest diameters for the most part at right angles to the direction of the other elements, oppose radial shrinkage and tend to produce longitudinal shrinkage of wood. Only in the tangential direction are these otherwise opposing forces parallel. For this reason as well as the fact that the denser bands of late wood are tangentially continuous, while radially they are separated by alternate zones of less dense early wood, wood usually shrinks more than twice as much tangentially as it does radially. In all cases, however, shrinkage parallel to the vertical axis is very slight, one-tenth to one-third of one per cent, and is maximum in woods with curly or wavy grain or with large or very abundant rays.

The following table gives the results of a series of shrinkage

tests made by Mr. Hugh P. Baker at the Yale Forest School. The figures given represent the average shrinkage resulting from reducing green wood to a kiln-dry condition and are computed on the basis of the original measurements.

TABLE IV

SHRINKAGE OF WOOD ALONG DIFFERENT DIMENSIONS

SPECIES.	Length %	Radius %	Diameter %	Circumference %	Area of cross section %	Volume %
Juniperus virginiana	0.32	2.7	2.5	5.6	6.9	5.9
Castanea dentata	.25	3.0	3.2	4.9	11.2	....
Quercus rubra	.24	3.7	3.5	8.2	10.4	....
Hicoria alba	.04	7.4	7.5	9.2	19.4	19.8
Juglans cinerea	.36	2.9	3.1	6.9	7.3	7.6
Liriodendron tulipifera	.15	4.3	4.8	9.3	12.6	13.7
Nyssa sylvatica	.10	6.1	6.2	11.5	17.1	18.0

Irregularities in shrinkage tend to cause wood to become distorted or *warped.* In woods with straight grain and uniform texture the tendency to warp is minimum unless the distribution of the moisture content is very unequal. Thus the upper surface of a green board exposed to the hot rays of the sun will dry much more rapidly, and therefore becomes shorter than the lower side, causing the board to curl up at the ends. Woods with interlaced fibres or with cross or spiral grain (*e.g., Nyssa, Liquidambar, Eucalyptus*) always shrink unequally, and consequently require careful handling in drying to prevent serious deformation. Warping due to unequal distribution of moisture may subsequently be overcome by thorough drying, but the deformation resulting from great irregularity of structure is usually permanent.

In Fig. 15 is shown in somewhat exaggerated manner the deformation caused by the greater tangential shrinkage. The flat side of a log cut through the middle becomes convex (*B*). Boards cut from half of a log assume the form shown in (*C*), while a plank from the middle of a log becomes convex on both sides. This explains most of the difference in shrinkage of timbers and boards of different sizes, shapes, and manner of sawing (*i.e.,* whether plain or quarter-sawed).

When the strains due to unequal shrinkage can no longer

be accommodated by the plasticity of the wood substance, cracks or checks are formed. These are most common along the rays, since there the strains are greatest and most complex. However, when the strength of the rays is greater than the cohesive force of the cementing substance uniting the two layers of the primary cell wall, radial fracture passes through the median plane of the primary wall of the wood cells instead of along the ray.

Variation in moisture content due to irregular drying results in checks, most of which are temporary, and as equilibrium becomes again established gradually close and become imperceptible. The more rapidly wood is dried, the greater is the tendency to check, for even if evaporation could be controlled so as to proceed uniformly throughout the specimen, the cells would not be given sufficient time to adjust themselves to the

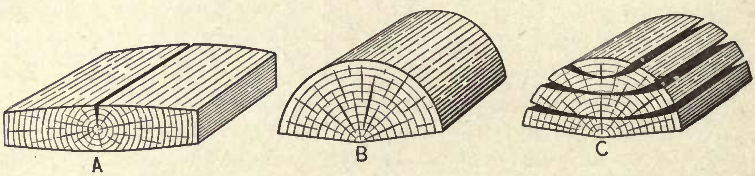

FIG. 15.

FIG. 15.—Effects of shrinkage. *A*, plank cut from middle of log (boxed heart), showing double-convex surfaces and large season check through upper half. *B*, log cut in half, showing the flat surface becoming convex and the appearance of three large season checks. *C*, half of a log cut into boards showing warping.

changed conditions. The presence of checks in wood, no matter how imperceptible, always impairs the strength of the material.

If the outer portion of a piece of wood, especially hard wood, dries much more rapidly than the inner, a hard shell is formed on the outside, while the interior retains most of its original moisture. This condition is known as *case-hardening*. This dry shell resists the transpiration of the moisture from the interior and retards drying, besides increasing the strains on the fibres. When the interior finally dries, the internal strains frequently become so great that large checks open up, producing a *honeycombed* condition.

Checks which result from greater shrinkage along the tangent than along the radius are permanent and increase in size as drying progresses (Figs. 1; 15 *B*). They cause serious difficulty in seasoning large timbers and especially material in the round, such as

logs, poles, and posts. If seasoned too rapidly hardwood timbers may split entirely open so as completely to destroy their value. In handling such material it is a common practice to forestall such checking by driving in *S*-shaped metal wedges across the incipient cracks. Such damage can also be reduced by more careful piling and handling of the material.

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HYGROSCOPICITY

Wood substance has the property of absorbing moisture from the atmosphere. When artificially dried wood is exposed to the open air it will increase in weight, due to the addition of hygroscopic water. Although the amount of water thus attracted is always greater than in the surrounding air, it does not remain constant, but varies with the humidity, and is equal to 8 to 16 (average 12) per cent of the dry weight of the wood. These variations are accompanied by proportionate changes in volume, that is, the wood alternately shrinks and swells, or "works." Hygroscopicity can be reduced, but not entirely eliminated, by subjecting wood to boiling, steaming, prolonged soaking, or exposure to high temperature.

This property of wood is a serious hindrance to its use in certain positions where exact fitting is permanently desired. Drawers and doors "stick" in damp weather, and become loose in dry weather, or when artificially heated and dried for con-

siderable time. Furniture, wainscoting, interior finish, and cabinet work may be badly damaged by prolonged drying, which opens up joints, loosens tenons, and causes veneers to separate from their backing. This property may be largely overcome by soaking wood in oil or coating the surface with paint, oil, or varnish, which excludes most of the air and moisture and keeps the condition of the wood uniform. Light, porous woods "work" less than dense woods. On account of their greater porosity and lightness, slowly grown ring-porous woods (Fig. 13) shrink and swell less than specimens of the same species more rapidly grown (Fig. 14).

The presence of natural oils, gums, and pigments such as are commonly found in the heartwood of many species usually reduces the hygroscopicity of woods.

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PERMEABILITY

In all green wood the cells are separated from each other by a thin membrane, the primary cell wall. The only important exceptions are the vessels between whose segments there is free communication vertically. Vessels, however, like other cells, are separated from each other and from other elements by the primary wall. This wall ordinarily persists intact unless ruptured by parenchymatous outgrowths—tyloses. It is permeable by water and certain dilute solutions which filter through slowly, but is impervious to oils and resins. Gases can enter into living cells only by going into solution, and in that condition diosmosing through the cell wall.

These facts have an important bearing on the process of impregnating wood with preservatives to prevent decay. It is not difficult to force gases or fluids through open vessels of green wood, but it is impossible to do so if they are plugged with tyloses. For example, it is very easy to blow through the vessels of green wood of most red or black oaks, even in pieces of considerable length. In green wood of the white oaks, on the other hand,

it is impossible to force any air through the vessels, even for short lengths and with very high pressure, since in this case they are blocked with tyloses. Even in the red or black oaks, however, air cannot be forced through the other elements of green wood.

When wood becomes dry its penetrability by both gases and liquids is increased to a remarkable extent. The same specimen of white oak which, while green, effectually withstood an air pressure of 150 pounds per square inch will, when dry, allow the passage of air, not only through the vessels, but also the other elements, under a pressure of 5 pounds per square inch or less. Similar effects are produced by drying any wood beyond its fibre-saturation point. This fact emphasizes the great importance of seasoning wood before attempting to impregnate it with preservatives.

According to Tiemann (*loc. cit.*), the explanation of this is that the drying of the cell walls causes minute checks or slits to occur in the primary walls. The dryer the wood becomes the larger the slits and the more permeable the wood. These slits do not entirely close when the wood is resoaked, so that wood once dried cannot be restored to its original condition.

Steaming is said to produce similar results, though the slits apparently are not as wide as when wood is air-dried. It is probable, however, that the maximum amount of slitting would result from thoroughly drying wood that had been previously steamed. Boiling green wood in oil results in more or less seasoning of the outer portions, thus allowing some penetration by the oil.

Dry woods, however, differ greatly in penetrability. Light, porous woods as a rule are much easier to impregnate than dense, compact ones. Heartwood of any species offers more resistance than the sapwood, due probably to the presence in the walls of gums, resins, and other infiltrations. Tyloses, which always reduce penetrability, are mostly absent from the outer portion of sapwood even when very abundant in the heartwood of the same tree. In the wood of Gymnosperms it appears that the wood-parenchyma cells are more penetrable than the tracheids. Open resin ducts permit the entrance of fluids into the body of the wood, behaving in a manner similar to the vessels of Dicotyledons.

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CONDUCTIVITY

Dry wood is a very poor conductor of heat, as is well illustrated in its use for matches and as handles for utensils and tools subjected to various temperatures. Increase in density or in moisture content increases the conductivity of wood. Woods are most conductive in direction parallel to the grain and least so in radial direction, the ratio in some instances being as high as 2 to 1. The difference between radial and tangential directions in this regard is slight, and is probably due to the fact that in a tangential direction the bands of the denser and therefore more conductive late wood are continuous, while radially they are interrupted by alternate bands of the less dense early wood.

Wood in a dry condition is a non-conductor of electricity. Increase of water content reduces its value as an insulator. Light, porous woods are more resistant to the passage of electric currents than are dense woods; highly resinous woods, more than woods without resin, since resin and oil are poor conductors of electricity.

Wood is a good conductor of sound, particularly in a longitudinal direction. The denser, the more uniform, and the dryer the wood the greater is its ability to transmit sound. Unsoundness and decay materially reduce this property.

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RESONANCE

"If a log or scantling is struck with the ax or hammer, a sound is emitted which varies in pitch and character with the

shape and size of the stick, and also with the kind and condition of wood. Not only can sound be produced by a direct blow, but a thin board may be set vibrating and be made to give a tone by merely producing a suitable tone in its vicinity. The vibrations of the air, caused by the motion of the strings of the piano, communicate themselves to the board, which vibrates in the same intervals as the string and reënforces the note. The note which a given piece of wood may emit varies in pitch directly with the elasticity, and indirectly with the weight, of the wood. The ability of a properly shaped sounding-board to respond freely to all the notes within the range of an instrument, as well as to reflect the character of the notes thus emitted (*i.e.*, whether melodious or not), depends, first on the structure of the wood, and next on the uniformity of the same throughout the board. In the manufacture of musical instruments all wood containing defects, knots, cross grain, resinous tracts, alternations of wide and narrow rings, and all wood in which summer and spring wood are strongly contrasted in structure and variable in their proportions are rejected, and only radial sections (quarter-sawed, or split) of wood of uniform structure and growth are used.

"The irregularity in structure, due to the presence of relatively large pores and pith rays, excludes almost all our broad-leaved woods from such use, while the number of eligible woods among conifers is limited by the necessity of combining sufficient strength with uniformity in structure, absence of too pronounced bands of summer wood, and relative freedom from resin.

"Spruce is the favored resonance wood; it is used for sounding-boards both in pianos and violins, while for the resistant back and sides of the latter, the highly elastic hard maple is used. Preferably resonance wood is not bent to assume the final form; the belly of a violin is shaped from a thicker piece, so that every fiber is in the original in as nearly an unstrained condition as possible, and therefore free to vibrate. All wood for musical instruments is, of course, well seasoned, the final drying in kiln or warm room being preceded by careful seasoning at ordinary temperatures often for as many as seven years or more. The improvement of violins, not by age, but by long usage, is probably due, not only to the adjustment of the numerous component parts to each other, but also to a change in the wood itself; years of vibrating enabling any given part to vibrate much more readily." *

* Roth, F., Timber, Bul. 10, U. S. Div. For., pp. 24–25.

COLOR

When wood is first formed it is almost, if not entirely, colorless, as may be observed in the outermost growth rings in any species. After a year or two it usually becomes yellowish, and still later when changed into heartwood a decided deepening of color results. Exceptions to this rule are rather numerous, for example, *Picea, Tsuga, Abies, Salix, Alnus, Betula, Ilex,* and *Æsculus* exhibit little or no contrast in color between heartwood and sapwood. In all species the sapwood has a very limited range of color and shade, but the heartwood exhibits great variation, from the chalky white of *Ilex opaca* to the ebony black of old *Diospyros virginiana,* with practically all intermediate colors, shades, and tints. In many woods the demarcation in color between heartwood and sapwood is very sharp and distinct, while in others the transition is gradual. In some instances (*e.g., Sequoia, Ilex, Catalpa, Cladrastis lutea*) the color is uniform, while in others (*e.g., Liriodendron, Liquidambar, Swietenia*) it is variable not only in different specimens, but in different portions of the same piece. The golden yellow of *Toxylon* shows narrow streaks of red; *Liquidambar* shows black streaks that usually give the finished lumber a handsome watered effect; *Liriodendron* varies from deep iridescent blue to yellowish brown; *Robinia* varies from light straw-colored to deep golden yellow like *Toxylon; Taxodium* is sometimes nearly black, often yellowish, reddish, brown, or mottled. The deep-colored wood of *Juniperus* frequently exhibits streaks of white sapwood, the intermingling resulting from the fluted periphery of the stem.

It is generally true that depth of color of woods is a criterion of durability. Thus the dark heartwood of *Juniperus, Sequoia, Prosopis, Toxylon, Robinia,* and *Morus* is very resistant to decay, while that of *Salix, Populus, Tilia, Æsculus, Acer, Fraxinus,* and *Nyssa* is perishable. The deeper color of the heartwood is due to the infiltration or deposition in the cell walls and lumina of gums, resins, pigments, tannin, and other substances. To these is ascribed the greater durability of wood, since sapwood is invariably not durable under exposure. In some instances, however (*e.g., Chamæcyparis, Taxodium, Catalpa, Sassafras*), the infiltrated substances tend to prevent decay without greatly deepening the color of the heartwood.

Color adds greatly to the value of wood for interior finish, cabinet work, marquetry, and parquetry. It is a very common practice to stain wood artificially. Light-colored and therefore less valuable wood of mahogany, such as commonly grows in the United States and Mexico, is often darkened; *Ilex opaca* is readily stained black to resemble ebony; *Betula lenta*, when properly stained, is a good imitation of mahogany; in fact, by the application of stains and finishes the variations in color and shade that can be produced in woods is practically unlimited. It is also possible by the introduction of certain chemicals to color the sapwood of a living tree.

For some uses of wood lack of color is prized. This is especially true of pulpwood, since coloring matter, if present, must be bleached out. Color is also undesirable in certain grades of flooring. In handles and spokes dark color is considered a defect, since it indicates heartwood, which is usually (but erroneously) thought to be weaker than the colorless sapwood.

All woods darken upon exposure to the atmosphere, probably due to the oxidation of the coloring matters. The rich golden yellow of *Toxylon* and *Morus* becomes a dark or russet brown; the sapwood of *Alnus oregona* turns reddish brown; *Pinus monticola* and *P. strobus* often become vinous red, especially near the end of an exposed piece of wood. On this account the natural color of a wood can only be seen on fresh-cut sections. Prolonged immersion in water causes wood to darken—some turning gray, others almost black.

Some woods (*e.g.*, *Cladrastis lutea*, *Prosopis*, *Sequoia*, *Juglans*) impart color to water in which they are soaked. The color of many others can be removed by treatment with NaOH or other chemicals, but it is often necessary to reduce the wood to pulp before it can be bleached. Many tropical woods (*e.g.*, *Clorophora tinctoria*, *Hæmatoxylon campechianum*, *Cæsalpina*, *Pterocarpus*) contain coloring principles of value in the arts for dyeing, though they have been largely superseded by aniline dyes. Of indigenous woods, *Toxylon pomiferum* and several species of *Xanthoxylum* are sometimes employed for this purpose, usually as adulterants of old fustic (*Clorophora*).

Color is often of great assistance for diagnostic purposes, though the range of variation and difficulty of description must always be taken into consideration. Unless otherwise stated, the colors mentioned in the key refer always to the fresh cross section

of a piece of dry wood. The character of the demarcation in color between heartwood and sapwood, whether sharp or gradual, is often an important feature, though usually not exhibited on very small specimens. The character and amount of coloring matter extracted by treatment with NaOH is sometimes made use of in identification.

Abnormal discoloration of wood usually denotes disease. The black check in *Tsuga heterophylla* is the result of insect attacks. The reddish-brown streaks so common in *Hicoria* are mostly the result of injury by birds. The bluing of the sapwood of many soft woods is due to the attacks of fungi. Many fungi can be determined specifically by the characteristic color they impart to wood.

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GLOSS OR LUSTRE

Gloss or lustre of wood refers to the manner in which light is reflected by the wood elements. The fibres of the bast are more lustrous than the wood fibres. The fibre of flax is highly lustrous, while that of cotton is dull. Similar variation occurs in the elements of different woods. For example, the woods of *Fagara*, *Rhus*, and *Toxylon* are highly lustrous; those of *Acer*, *Betula*, and *Robinia* less so; while those of *Juglans nigra*, *Sequoia*, *Fagus*, and *Platanus* are dull. The wood of *Picea* possesses a pearly lustre; that of *Guaiacum* and *Taxodium* is rather greasy or waxy. In some cases the lustre varies in different parts of the wood or on different planes. The late wood of *Juniperus virginiana* exhibits a frosted lustre on tangential surface. The rays on quarter-sawed wood of several species, particularly the oaks, are so lustrous in contrast to the other elements as to give rise to the term "silver grain," while the rays themselves are called "mirrors." Woods with high natural lustre are usually capable of taking a high polish. Lustre is a sign of soundness

in wood, for incipient decay causes wood to become dull and "dead." Sound wood in thin sections is translucent and exhibits double refraction. The presence of rosin in wood increases its translucency.

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SCENT OR ODOR

Every wood when fresh possesses in some degree a characteristic scent, though in a great many cases it is so weak or fleeting that it escapes notice. Odor depends upon chemical compounds (*e.g.*, ethereal oils and tannin) which form no part of the wood itself. Ordinarily it is more pronounced in heartwood than in sapwood. It is also greater in wood in a green condition than when seasoned, more evident on moist surfaces than on dry. Upon prolonged exposure to air, or when submerged in water, wood gradually loses its scent. In some cases the loss is complete throughout; in others only the outer portions are affected. Woods deriving their odors from the presence of ethereal oils, as is the case in many cedars, apparently may be kept indefinitely and still emit their characteristic odors when a fresh surface is exposed.

Upon exposure to the air for a short time some green woods (*e.g.*, *Quercus*) acquire a disagreeable, soured odor, probably due to the decomposition of certain organic compounds. Woods in process of decay emit various odors, sometimes very disagreeable (*e.g.*, *Populus*), sometimes not unpleasant (*e.g.*, *Quercus*), but always different from the natural scent characteristic of the sound wood.

The fumes of burning wood are occasionally characteristic. Resinous woods, as *Pinus*, give off an odor of tar. The woods of *Juniperus virginiana* and *Chamæcyparis lawsoniana* burn with a pungent, spicy scent, giving the latter a special value for matchsticks. The woods of *Cercidium* and *Parkinsonia* give off very penetrating, disagreeable fumes when burned, reducing materially their desirability for fuel.

The scent of certain woods renders them commercially valuable. Cigars are believed to be considerably improved by being kept in

cedar boxes. The scent of cedar (*Juniperus virginiana, Chamæcyparis lawsoniana,* and *C. nootkatensis*) is apparently disagreeable to moths and other insects, making the wood desirable for cabinets, wardrobes, chests, and drawers where furs and woolen clothes are kept. Cedar shavings are also employed for the same purpose. Loss of scent from the exposed surface of the wood soon seriously impairs the efficiency of the wood for this purpose. For some purposes, especially as receptacles for wines, liquors, drinking-water, and oils, meats, fish, butter, and other foodstuffs, highly-scented wood is undesirable since it is apt to taint the contents.

While scent is often a very valuable aid to the identification of wood, its utility is lessened by the difficulty and often impossibility of describing an odor so that one unfamiliar with it would be able to recognize it. Such descriptions are necessarily limited to comparisons with well-known scents which are usually inadequate. The scent of the wood of *Pinus* is resinous or like turpentine; that of *Juniperus* and *Chamæcyparis thyoides* aromatic, like cedar oil; that of *Chamæcyparis nootkatensis, C. lawsoniana,* and *Libocedrus decurrens* spicy-resinous; that of dark-colored, waxy specimens of *Taxodium,* like rancid butter; that of *Catalpa* somewhat like kerosene; that of *Viburnum lentago* and *V. prunifolium* very disagreeable and pungent.

The following genera and species usually can be recognized by their odor alone: *Juniperus, Chamæcyparis thyoides, C. lawsoniana, Libocedrus, Thuya, Tsuga canadensis, Sassafras, Viburnum,* and *Catalpa.* With a keen sense of smell others may be recognized; for example, *Pinus, Taxodium, Quercus, Castanea, Ulmus,* and *Betula.* Prominent among exotic species characterized by pronounced scents are the camphor trees (*Cinnamomum camphora, Dryobalanus camphora, Camphora glanduliferum*), Indian sandalwood (*Santalum album*), and violet-wood (*Acacia homophylla*).

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TASTE

Wood substance itself, being insoluble in water or weak alkaline solutions, is necessarily tasteless. The characteristic taste of certain woods is due then to soluble substances deposited in the cell lumina or infiltrated into the cell walls. In any wood the most pronounced flavor is obtained from the sapwood; it is also more pronounced in green material than in dry. This is probably due to the fact that the substances giving wood its flavor were in solution or soluble form in the living sapwood. When submerged in water they may be leached out, and when exposed to air, oxidized.

Taste is occasionally helpful in identifying woods, though, like odor, it cannot be described with accuracy. The wood of *Libocedrus decurrens* has a very spicy flavor; that of *Pinus palustris* terebinthic; that of *Chamœcyparis lawsoniana* spicy-resinous; that of *Sassafras* rather spicy. The wood of *Castanea* has no special flavor, but on account of the tannin in it, has an astringent effect on the mouth.

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PART II

KEY TO THE ECONOMIC WOODS OF THE UNITED STATES

EXPLANATORY NOTES

The descriptive key given in the following pages is based upon features visible with the unaided eye and with a small hand lens, and also upon features visible only under the compound microscope. The latter are indicated by smaller type.

The small numerals following the names of the woods refer to a list of references on pp. 109–117.

The capitals in parentheses following the specific names refer to the regions indicated on the map (Plate I, Natural Forest Regions of the United States) and indicate in a general way the natural distribution of the species:

(P), Pacific Coast Forest; (R), Rocky Mountain Forest; (N), Northern Forest; (C), Central Hardwood Forest; (S), Southern Forest; (T), Tropical or Sub-tropical Forest; (n), north; (s), south; (Int.), Introduced into the United States. Where more than one region is indicated the more important is placed first.

I. Non-porous Woods: Gymnosperms, Conifers, Soft-woods. (For II, see p. 85.)

Vessels absent. Woods comparatively homogeneous; composed mostly of tracheids fairly uniform in structure and arranged in definite radial rows; barely visible under lens. Growth rings usually quite distinct on account of the abrupt change in density and in color between the late wood of one year's growth and the early wood of the next (see p. 40). Wood parenchyma (resin cells) and resin ducts present or absent. Rays very fine, scarcely visible without a lens. Woods with or without pronounced resinous odor and taste.

A Resin ducts, both vertical and horizontal (fusiform rays), present; scattered *; the vertical appearing on longitudinal surface as fine lines or scratches, light or dark in color. Rays with tracheids. (For B, see p. 80.)

a Resin ducts plainly visible without lens; numerous to moderately so, and fairly well distributed. (For **b**, see p. 78.)

a¹ Tracheids normally without spirals. Resin ducts not constricted but often closed with tylosal outgrowths of the epithelial cells; the latter are thin-walled and normally flattened. Wood parenchyma only in association with resin ducts, not isolated or zonate. Ray tracheids comparatively large and numerous, in one to several marginal rows and frequently interspersed in high rays and often entirely composing low rays. Woods with characteristic but not always pronounced resinous odor. Color contrast between heartwood and sapwood usually sharp and distinct. (For **b¹**, see p. 77.) **Pine.**[1]

a² Moderate contrast in color and density between seasonal growths; transition between the two portions of growth ring gradual; texture uniform. Woods soft to medium, comparatively non-resinous. Color pale straw to reddish-brown. Ray tracheids with upper and lower walls uniformly thickened or smooth (Figs. 4, 5, pp. 25–26). Pits present in the tangential walls of the late wood. **Soft Pine Group.**

a³ Woods soft, straight-grained. Ray parenchyma cells in early wood with 1 or 2 large simple pits in each cross-field.† (Fig. 4, p. 25.)

White or Five-leaved Pine Group.‡[2]

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* As a result of injury, compact peripheral rows of ducts may arise as in the case of certain woods in which resin ducts do not occur normally.

† By "cross-field" is meant the area of intersection of a ray cell and a wood tracheid. The typical condition of pitting is found only in the early wood as the pits may be semi-bordered in the summer wood.

‡ The other members of this group (**a³**) are *P. flexilis* James (P), *P. albicaulis* Eng. (R, P), and *P. strobiformis* Eng. (R). Their woods are of no commercial importance. That of *P. albicaulis* is characterized by resinous tracheids. See author's "Significance of Resinous Tracheids," Botanical Gazette, 66: 1: 61–67 (July, 1918).

a[4] Color varying from light straw or creamy-white to reddish-brown, more pronounced in summer wood and deepening upon exposure to sunlight. Texture comparatively fine. Lustre silky. Wood readily cleavable into long thin strips. Resin ducts fairly conspicuous, especially in second-growth, appearing on longitudinal surface as straw-colored or light-brown lines. No sugary exudations. Sp. gr. .35–.43. **(Eastern) White Pine, Northern Pine,** *Pinus strobus* L. (N)[3]; **Western** or **Idaho White Pine,** *P. monticola* Dougl. (P).

b[4] Color yellowish-white to very light brown, never deeply reddish; brown stain common. Texture coarse. Lustre dull. Wood not readily cleavable into long thin strips. Resin ducts conspicuous and usually dark-colored. Sugary exudations and sugar pockets common on fresh lumber. Sp. gr. .32–.40. **Sugar Pine,** *P. lambertiana* Dougl. (P).[4]

b[3] Wood rather hard, cross-grained, fine-textured. Color yellowish, uneven, not very distinct from sapwood. Odor often like beeswax. Sp. gr. .45–.67. Ray parenchyma cells with 3–6 small piciform * pits in each cross-field. (Fig. 5, p. 26.)

Foxtail and Nut Pine Group.

Piñon pine, *P. edulis* Eng. (R).†[5]

b[2] Decided contrast in density and usually in color between seasonal growths; transition between the two portions of a growth ring usually abrupt; texture variable, often very uneven. Woods varying from very hard to soft; moderately to highly resinous. Color variable, but mostly darker than in soft pines. Ray tracheids, which often predominate in ray, with upper and

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* Pit with lenticular opening and small circular border as in rays of *Picea*.

† Microscopic structures for this group apply also to *P. quadrifolia* Parl. (P), *P. cembroides* Zucc. (R), *P. monophylla* T. & F. (R), *P. balfouriana* Murr. (P), *P. aristata* Eng. (P). These woods are not of commercial importance.

lower walls irregularly thickened, dentate to reticulate * (Figs. 6, 7, pp. 27–28). Pits rarely present in tangential walls of the late wood. **Pitch Pine Group.**

a[3] Ray parenchyma cells in early wood with 1 or 2 large simple pits in each cross-field (Fig. 6, p. 27). Wood rather light and soft, variable, fairly strong, medium-textured, not highly resinous. Sp. gr. .42–.54. **Red Pine Group.**† **Red or Norway Pine,** *P. resinosa* Ait. (L).[6]

b[3] Ray parenchyma cells in early wood with 3–6 (occasionally more) small, irregular, simple (rarely semi-bordered) pits in each cross-field (Fig. 7, p. 28). **Yellow Pine Group.**

a[4] Woods variable from light and soft to moderately heavy and hard. **Western Pines.**

a[5] Wood fairly uniform, soft, not highly resinous, light-colored. Sp. gr. .35–.47. Tangential surface showing conspicuous "pebbly" or "dimpled" grain. **Lodgepole Pine,** *P. contorta* Loud., or *P. murrayana* "O.C." (R, P).[7]

b[5] Wood variable from light, soft, non-resinous, and nearly white to fairly heavy, hard, resinous, and reddish-brown in color. Sp. gr. .39–.60. "Pebbly" grain not characteristic though occasionally present. **Western Yellow Pine, Western Pine, California, New Mexico or Arizona White Pine, Western Soft Pine, Bull Pine,** *P. ponderosa* Laws.‡ (R, P).[8]

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* The very irregular thickenings of the upper and lower walls of the ray tracheids are peculiar to the pitch pines. Spiral markings and other irregularities of the wall found occasionally in the ray tracheids of certain other conifers are quite distinct from the heavy sculpturing in the ray tracheids of the pitch pines.

† The microscopic structure of *P. resinosa* characterizes also one Asiatic and two European pines which are being planted to some extent in the United States, namely, Japanese Red Pine, *P. densiflora* S. & Z., Scotch Pine, *P. sylvestris* L., and Austrian Pine, *P. laricio* Poir.

‡ Included under this name are closely related forms whose woods are not distinguishable. The softest grades of the wood are from the outer portions of large, over-mature timber.

b4 Woods varying from moderately to extremely heavy and hard. **Southern Pines.***[9]

a5 Woods usually very dense and resinous, with large proportion of sharply defined late wood.

a6 Growth rings mostly wide, variable. Sapwood thick. Sp. gr. .50–.90, usually between .65 and .75. **Slash** or **Cuban Pine,** *P. caribaea* Mor., *P. heterophylla* (Ell.) Sudw., or *P. cubensis* Gris. (S).[10]

b6 Growth rings mostly narrow beyond first 2 or 3 inches of radius, fairly uniform. Sapwood thin. Sp. gr. .50–.90, usually between .60 and .70. **Longleaf Pine, Georgia Pine,** *P. palustris* Mill., or *P. australis* Michx. f. (S).[11]

b5 Woods usually moderately dense and resinous, widely variable; medium to small proportion of late wood not always sharply defined.

a6 Growth rings variable, narrow to extremely broad. Sapwood thick. Sp. gr. .40–.80, usually between .45 and .55. **Loblolly** or **North Carolina Pine,** *P. taeda* L. (S).[12]

b6 Growth rings fairly regular, broad toward pith and narrow beyond 5–7 inches. Sapwood rather thick. Sp. gr. .40–.80, usually between .45 and .55. **Shortleaf Pine,** *P. echinata* Mill., or *P. mitis* Michx. (S).[13]

b1 Tracheids normally with spirals.† Resin ducts widely variable in size and arranged often in short tangential groups; ducts con-

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* Specific identification of the southern pines is very uncertain. Since the mechanical and physical properties of the woods are factors of the density, classification for commercial purposes is made on that basis.

† The spirals in the tracheids serve to distinguish the wood of *Pseudotsuga* from that of all others resembling it. The tracheids of *Taxus* and *Tumion* are spiralled but the woods are wholly devoid of wood parenchyma, resin ducts, and ray tracheids. The sporadic occurrence of true spirals in *Picea*, *Larix* and *Pinus* has been noted and in the rare instances where such is the case the other anatomical features must be taken into account. Spirals, which are thickenings upon the inside of the secondary wall, must not be confused with striations which are slits or cracks running spirally in the thick walls of the late wood and of "compression wood" (rotholz) of many conifers.

stricted at intervals but rarely closed by tylosal outgrowths of the epithelial cells; the latter are usually small, thick-walled, rounded. Isolated wood parenchyma strands (resin cells) occasionally found. Ray tracheids small, usually in single marginal rows, sometimes showing minute spirals. Ray parenchyma pits small and more or less piciform. Wood resembles that of Southern Pines but for the most part is without very pronounced resinous odor, usually less pitchy, and on radial surface usually shows less distinct color contrast between seasonal growths. Color contrast between heartwood and sapwood distinct. Sp. gr. .39–.68, mostly between .45 and .55. Growth rings more or less undulating, showing on both cross and longitudinal surfaces. Wood of two general classes: (1) Fine-grained, fairly uniform-textured, moderately light and soft, easy to work; color pale reddish-yellow; hence the local name of "yellow fir." (2) Coarse-grained, uneven-textured; early wood open and weak, late wood dense and flinty; color rather deep red, hence the local name of "red fir." **Douglas Fir, Spruce** or **Pine, Oregon Pine,** *Pseudotsuga taxifolia* Brit., *P. douglasii* Carr., or *P. mucronata* (Raf.) Sudw. (P, R).[14]

b Resin ducts mostly small, inconspicuous, widely scattered or in small tangential groups; appearing in late wood commonly as small whitish dots; usually open; epithelial cells small, normally thick-walled, rounded. Isolated wood parenchyma strands (resin cells) rare; terminal. Tracheids rarely with spirals. Ray tracheids small, usually in single marginal rows, rarely with spirals. Ray parenchyma cells thick-walled, abundantly pitted in upper, lower and end walls; pits on lateral walls lenticular or slit-like, small, semi-bordered, 2–6 in each cross-field in early wood.*

a^1 Wood variable, but mostly hard and heavy, with decided contrast between seasonal growths; sometimes decidedly pitchy. Sapwood thin with distinct line of demarcation. **Larch.**[15]

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* The woods of larch and spruce bear considerable resemblance microscopically to the woods of the foxtail and nut pine group. They can usually be readily distinguished by the nature of the epithelial cells of the resin ducts, being thin-walled and flattened in the pines and, with occasional exceptions, thick-walled and rounded in the others. This is seen to best advantage in the fusiform rays (tangential section).

a^2 Color yellowish-brown, not reddish. Texture medium. Wood usually in small sizes, not straight-grained, not highly resinous. Sp. gr. .54–.78, mostly between .55 and .65. **Larch, Tamarack, Hackmatack,** *Larix laricina* (Du Roi) Koch., or *L. americana* Michx. (N).

b^2 Color red to reddish-brown. Texture coarse and harsh. Wood obtainable in large sizes, straight-grained, sometimes extremely dense and very pitchy. Sp. gr. .59–.83, mostly between .60 and .70. **Western Larch, Tamarack,** *L. occidentalis* Nutt. (R).

b^1 Wood varying from very light and soft to moderately so, with from slight to decided contrast between seasonal growths; non-resinous. Texture fine. Lustre satiny and finely dappled, especially on tangential surface. Sapwood usually without distinct line of demarcation. **Spruce.**[16]

a^2 Color white or very light, uniform, with little or no contrast between heartwood and sapwood. Resin ducts scarcely visible without lens. Sp. gr. .31–.53, mostly between .35 and .45.

a^3 Grain varying from extremely fine to medium.* **Red Spruce,** *Picea rubens* Sarg., or *P. rubra* Diet. (N)[17]; **Black Spruce,** *P. mariana* Mill., or *P. nigra* Link. (N).

b^3 Grain mostly coarse. **White** or **Cat Spruce,** *P. canadensis* (Mill.) B. S. P., or *P. alba* Link. (N) †; **Engelmann Spruce,** *P. engelmanni* Eng. (R).

b^2 Color reddish or pinkish, fading gradually outward into sapwood; deepest in rays. Texture rather wooly. Resin ducts fairly distinct. Sp. gr. .34–.65, mostly between .35 and .40. **Sitka Spruce,** *P. sitchensis* (Bong.) T. & M. (Pn).

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* Since fineness of grain (*i.e.*, width of growth rings) is largely determined by external factors it is an unreliable diagnostic feature and is resorted to here because constant features of distinction are apparently wanting and also because it is used to some extent by lumbermen.

† The wood of the eastern spruces, particularly *P. canadensis*, rather closely resembles that of the balsam fir, and the two are often associated both in the forest and in the market. The peculiar dappled lustre of spruce and the presence of resin ducts and ray tracheids are distinctive.

B Vertical resin ducts normally absent; may be present as result of injury in which event they are arranged in a compact peripheral row (Fig. 10, p. 32); horizontal resin ducts (fusiform rays) absent.* Ray tracheids present or absent.†

a Tracheids without spirals. (For **b**, see p. 85.)

a¹ Woods without aromatic odor. (For **b¹**, see p. 82.)

a² Resin cells absent or few; never visible without compound microscope. Color of woods not pronounced, though late wood exhibits a slight purplish tinge. Without sharp demarcation and with little color contrast between heartwood and sapwood.

a³ Ray tracheids normally absent. **Fir.**[18]

a⁴ Color white or pale brown in general appearance, with late wood rather purplish. Wood often coarse-grained, soft and weak. Sp. gr. .29–.45, mostly between .35 and .40. **Balsam** or **Balsam Fir,** *Abies balsamea* Mill. (N); **Lowland Fir,** *A. grandis* Lindl. (P); **White Firs,** *A. concolor* Parry (P) and *A. amabilis* Forb. (P).

b⁴ Color yellowish-brown with reddish tinge; rays decidedly reddish. Wood moderately to decidedly heavy and hard. Sp. gr. .41–.58. **Noble Fir,** *A. nobilis* Lindl. (P); **Red Fir,** *A. magnifica* Murr. (P).

b³ Ray tracheids present in single marginal rows and sometimes interspersed. **Hemlock.**[19]

a⁴ Odor disagreeable, though not very pronounced in small dry specimens. Wood harsh and slivery, inclined to split apart at growth rings;

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* Traumatic resin ducts occur occasionally in the woods of various species of *Abies*, of *Tsuga heterophylla*, both species of *Sequoia*, and certain species of *Cedrus*, but in no other genera of this group. Traumatic horizontal canals have been reported only for certain species of *Cedrus* and some extinct species of *Sequoia* (?) not included in this key.

† Small marginal ray tracheids are characteristic of *Tsuga*. No ray tracheids have been observed in *Taxodium*, *Tumion* (*Torreya*), and *Taxus*. Their more or less sporadic occurrence in *Abies*, *Sequoia*, *Chamæcyparis*, *Thuya*, *Juniperus*, and (very rarely) *Libocedrus* has been noted by the author or reported by others. (See W. P. Thompson, "Ray tracheids in *Abies*," Bot. Gaz., 53: 4: 331–338; also Ruth Holden, "Ray tracheids in the Coniferales," Bot. Gaz., 55: 1: 56–65).

brittle. Sp. gr. .33–.52, mostly between .40 and .45. Contrast between seasonal growths very pronounced; transition abrupt. Color light buff with reddish-brown tinge. No resin ducts or aggregates of resinous tracheids. **(Eastern) Hemlock,** *Tsuga canadensis* Carr. (N).

b⁴ Odorless when dry; green wood slightly sour-smelling. Wood of rather uniform texture, not particularly harsh and splintery, straight-grained and fairly easy to work. Sp. gr. .30–.57, mostly between .40 and .50. Transition from early wood to late wood rather gradual. Color light, sometimes pinkish or reddish-brown. Small black checks common. Aggregates of resinous tracheids, somewhat resembling resin ducts on cross section, fairly common; wound ducts in peripheral rows occasionally present. **Western Hemlock,** *T. heterophylla* Sarg. (P).[20]

b² Resin cells numerous, visible under hand lens and often collectively to unaided eye, particularly in sapwood; frequently zonate. Color of woods characteristic. Distinct demarcation between heartwood and sapwood.

a³ Color varying from light cherry-red to purplish. Texture rather coarse. Woods without odor or taste. Wound ducts sometimes present in peripheral rows. Resin masses in wood parenchyma strands appear under lens on longitudinal surface as rows of black or amber beads. Rays biseriate in part; occasionally with marginal or isolated ray tracheids; lateral pits in ray parenchyma cells large and, in early wood, horizontally elongated; no terminal pits. Bordered pits in tracheids of early wood commonly paired.

Sequoias.[21]

a⁴ Wood deeply colored, purplish or maroon. Growth rings usually very narrow. Texture uniform. Wood weak, brittle, and soft. Sp. gr. .25–.33. **Bigtree, Giant Sequoia,** *Sequoia washingtoniana* (Winsl.) Sudw., or *S. gigantea* Dec. (P).[22]

b⁴ Wood less deeply colored, mostly light cherry-red. Considerable variation in width of growth rings. Wood variable from light, soft and uniform-textured to fairly heavy, hard, and showing decided contrast between the two portions of a growth ring. Resin masses more prominent than in preceding. Sp. gr. .40–.52, mostly between .40 and .45. **Redwood,** *S. sempervirens* (Lamb.) Endl. (P).[23]

b³ Color widely variable, yellowish, reddish, brown, variegated, or almost black. Texture fine. Smooth surface of denser specimens usually looks and feels greasy or waxy, sometimes as though heavily impregnated with paraffine. Odor somewhat rancid or wanting. Wood variable from very soft and light to rather hard and heavy. Sp. gr. .34–.55, mostly between .40 and .50. No resin masses visible under lens; under compound microscope resin in wood parenchyma strands appears mostly in globular masses. Rays uniseriate, without tracheids; lateral pits in ray cells large and obliquely elongated; no terminal pits. Bordered pits in tracheids of spring wood rather small and often irregularly disposed or, near ends, arranged in pairs or in horizontal rows of 3 or 4. **Southern or Bald Cypress,*** *Taxodium distichum* Rich. (S).[24]

b¹ Woods with aromatic odor. **Cedar Group.**[25]

a² Color light clear yellow or slightly brownish, without much distinction between heartwood and sapwood. Late wood inconspicuous. Odor pronounced; pungent. Taste unpleasantly spicy-resinous. Woods varying from light and soft to moderately so. Texture fine, uniform. Sp. gr. .40–.54, average about .45. **Yellow Cedars.**

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* A varietal form, *T. distichum* var. *imbricarium* Sarg., is recognized by botanists but the wood is scarcely if at all distinguishable from the specific form. Lumbermen refer to different grades of wood as yellow, red, white, or black, sometimes in connection with the color, sometimes in reference to buoyancy of the logs. Cypress lumber is often "pecky" or "peggy," that is, filled with large fungous-galleries. The wood of the "knees" is extremely light, soft, and uniform-textured and is used commercially for floats. The tracheid walls are very thin, the cavities large, and the radial pits are considerably smaller than those in stem wood.

a^3 Color very light. Texture very fine. Odor moderately pronounced. Ray tracheids common in low rays. **Yellow Cedar, Yellow** or **Sitka Cypress,** *Chamæcyparis nootkatensis* Spach. (P).

b^3 Color deep yellow, sometimes brownish. Texture moderately fine. Odor very pronounced. Ray tracheids rarely present. **Port Orford Cedar, Lawson's Cypress, Oregon Cedar,** *C. lawsoniana* Parl. (P).

b^2 Color varying from light brown to purple, never yellow. Late wood distinct; often conspicuous. Odor variable, more or less pronounced, but not pungent. Taste not unpleasant.

a^3 Wood firm and compact, cutting smoothly across the grain. Moderate contrast between seasonal growths; transition gradual. Demarcation between heartwood and sapwood usually distinct.

Red Cedar Group.

a^4 Color pale reddish-brown or roseate, uniform; rays brown. Odor pronounced. Taste spicy. Resin cells fairly numerous, zonate, mostly in late wood; usually not visible with lens. Texture rather fine, uniform. Growth rings regular; late wood fairly conspicuous. Heartwood often "pecky" as in *Taxodium*. Sp. gr. .34–.46, mostly between .35 and .40. Rays not gummy; 1–8, mostly 3–5, cells high; ray tracheids absent. **Incense Cedar,** *Libocedrus decurrens* Torr. (P).[26]

b^4 Color purple or deep red, soon becoming dull brown upon exposure to sunlight; often streaked with white; rays deep red or purple. Odor and taste characteristic but mild; not sweetish or spicy. Resin cells very numerous, deeply colored, mostly zonate (Plate II, Fig. 3) in concentric lines visible with lens and often without it. Rays gummy, 1–20 cells high, very irregular. Texture very fine and uniform. Growth rings often very irregular in width and outline, frequently eccentric; summer wood not conspicuous, sometimes doubled or trebled. Wood

usually knotty except in very small sizes; never "pecky." Sp. gr. .45–.53, average about .49. Ray tracheids fairly common and (1) marginal, in which case they are of irregular shape or upright, or (2) constituting low rays entirely or in alternation with ray parenchyma cells. **Juniper, Red** or **Pencil Cedar,** *Juniperus virginiana* L. (N, C); **Southern Red Cedar,** *J. barbadensis* L. (S).*[27]

b[3] Wood soft and more or less spongy.

a[4] Decided contrast between seasonal growths; late wood thin but hard, early wood very soft; transition between the two portions of a growth ring abrupt. Sp. gr. .34–.42. Color varying from various shades of brown to decidedly reddish; often streaked. Resin cells inconspicuous, often zonate in widely separated growth rings. Bordered pits usually in pairs near ends of tracheids in early wood. **Western Red Cedar, Giant Arborvitæ, Canoe Cedar, Shingle Cedar,** *Thuya plicata* Don., or *T. gigantea* Nutt. (P).[28]

b[4] Moderate contrast between seasonal growths; late wood rather soft; transition between the two portions of a growth ring gradual. Color pale brown or pinkish, never very dark; little contrast between heartwood and sapwood. Resin cells zonate or diffuse. Bordered pits in tracheids rarely paired. **White Cedar Group.**

a[5] Color pale brown; intermingling of lighter and darker shades common. Resin cells rarely visible with lens. Odor very mild. Wood very soft and rather punky; brash. Growth rings mostly narrow. Sp. gr. .28–.37, average about .32. **Arborvitæ, Northern White Cedar,** *T. occidentalis* L. (N).

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* There are a number of western species of *Juniperus* but they are only of local importance. Their woods resemble the eastern species but are mostly harder and heavier, and the color of some of them is brown rather than deep red or purple.

b[5] Color light reddish-brown or pinkish. Concentric lines of resin cells visible with lens and often without it. Odor more pronounced and wood firmer and less brash than in preceding. Growth rings mostly moderately wide. Sp. gr. .30–.45, mostly between .30 and .35. **White Cedar,** *Chamæcyparis thyoides* (L.) B. S. P., or *C. sphæroidea* Spach. (N, S).

b Tracheids with spirals. Wood parenchyma (resin cells) and ray tracheids wholly absent. **Taxaceæ.***

a[1] Color reddish-brown to rose-red. Clear demarcation between heartwood and sapwood. Woods without odor.

a[2] Color bright orange to rose-red; thin sapwood pale yellow. Wood uniform and very dense. Sp. gr. .62–.70. Tracheids very small, thick-walled. **(Western) Yew,** *Taxus brevifolia* Nutt. (P).

b[2] Color brownish-red; thin sapwood nearly white. Wood somewhat less dense. Sp. gr. .63. Tracheids comparatively large and not so thick-walled as in preceding. **Florida Yew,** *T. floridana* Nutt. (S).

b[1] Color bright clear yellow, without pronounced demarcation between heartwood and sapwood. Wood with characteristic odor. Sp. gr. .44–.60, mostly around .50. **California Nutmeg,** *Tumion californicum* (Torr.) Greene, or *Torreya californica* Torr. (Ps); **Stinking Cedar,** *Tumion taxifolium* (Arn.) Greene, or *Torreya taxifolia* Arn. (S).

II. Porous Woods: Dicotyledons, Hardwoods, Broad-leaf Woods

Vessels present; varying in size from large and conspicuous to minute. Woods comparatively heterogeneous, being composed of several kinds of elements, mostly irregularly disposed. Growth rings varying from very distinct in the ring-porous woods to indistinct in some of the diffuse-porous. Wood parenchyma

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* The woods of the Taxaceæ are of very limited commercial importance because of their scarcity and small size.

present in variable amount; often conspicuous. Resin ducts absent. Gum ducts sometimes present in a few species. Rays varying from minute to large and conspicuous.

A RING–POROUS WOODS. Largest pores localized in a distinct ring or band in early wood.* (For **B**, see p. 95.)

a Late wood with *radial* lines or patches (frequently branched or fan-like) composed of small pores and parenchyma, usually lighter colored than remainder of wood; also with parenchyma in fine concentric lines, distinct to indistinct.† (For **b**, see p. 88.)

a¹ Rays all very fine, inconspicuous.‡ Woods soft to moderately hard; stiff but not strong; sp. gr. .45–.59.

a² Pores in early wood few, small, nearly circular, open, and rather widely separated in a single row. Color of wood light brown or roseate. Odorless and tasteless. Vessels without spirals; bordered pits circular, tending to become scalariform in small vessels; perforations simple with tendency to scalariform with few bars; pits into ray cells either half-bordered or simple. Rays uniseriate (occasionally biseriate in median portion), 5–15 cells high; slightly heterogeneous. **Western Chinquapin,** *Castanopsis chrysophylla* de C. (P).

b² Pores in early wood very numerous, large, mostly oval or elliptical, open, and in a broad zone. Color of wood brown; stains blue-black in contact with iron when moist. Odor of fresh wood mild but distinct. Taste somewhat astringent due to tannin content. (Microscopic features given in preceding apply here.) **Chestnut,§** *Castanea dentata* Borkh. (C, N).[29]

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* This feature may be obscure in very narrow growth rings where the proportion of late wood is so reduced that the wood appears diffuse-porous.

† The visibility of wood parenchyma is usually increased by moistening the smoothly cut end of the specimen.

‡ The distinctness of the rays refers to the cross section unless otherwise stated.

§ The chinquapin chestnut (*Castanea pumila* Mill.) is a small southern tree of only local importance for fence posts and fuel. The wood is mostly harder, heavier and of slower growth than the other species. The structures of the two woods are nearly identical.

b[1] Rays of two kinds: (1) large and conspicuous,* showing as broad flakes on radial surface and as distinct lines on the tangential; (2) very fine and inconspicuous, mostly invisible without lens. (See Plate III, Fig. 1.) Wood hard and heavy; usually very tough and strong; sp. gr. .65–.90. Odor of fresh wood characteristic. (Microscopic features given above also apply here, except as to size of rays.) **Oak.**†[30]

a[2] Pores in late wood individually distinct under lens and few enough to be readily counted; arranged mostly in fairly definite radial rows (except in narrow growth rings). Pores in early wood usually crowded in a broad zone and becoming gradually smaller outward (occasional exceptions). All pores usually open; sometimes partially or wholly filled with tyloses. Ray lines on tangential surface usually short (rarely exceeding 1 inch), and more or less interrupted by wood fibers. Color of wood typically pale reddish-brown, deeper near knots. Pores in late wood are thick-walled and more or less circular in outline. (Plate II, Fig. 6.) **Black and Red Oak Group. Red Oak,** *Quercus rubra* L. (C, N); **Black** or **Yellow Oak,** *Q. velutina* Lam. (C, N); **Spotted Oak,** *Q. texana* Buckl. (C, S); **Spanish Oak** or **Southern Red Oak,** *Q. digitata* Sudw., or *Q. falcata* Michx. (S, C); **Scarlet Oak,** *Q. coccinea* Muench. (C, N); **Pin Oak,** *Q. palustris* Muench. (C); **Black Jack,** *Q. marilandica* Muench. (C, S); **California Black Oak,** *Q. californica* (Torr.) Coop. (P); **Water Oak,** *Q. nigra* L. (S, C); **Laurel Oak,** *Q. laurifolia* Michx. (S); **Shingle Oak,** *Q. imbricaria* Michx. (C, N); **Willow Oak,** *Q. phellos* L. (S).

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* Occasional specimens of branches or of rather small stems are found which have few or no large rays. Oak wood is quite distinct, however, even when this prominent feature is wanting.

† The author is of the opinion that the features so far recognized as constant in the woods of the oaks will permit separation into general groups only. Fortunately, this classification corresponds very closely to the technical properties of the woods and this fact renders specific distinctions of much less importance.

b² Pores in late wood rarely individually distinct under lens and not few enough to be readily counted; arranged in fan-shaped patches often joined tangentially in outer portion. Pores in early wood in few (1–3) rows, usually not crowded; transition to small pores of summer wood abrupt;* usually closed with tyloses except in outer sapwood.† Ray lines on tangential surface often quite long (up to 5 inches) narrow, and straight. Color of wood pale to medium dark brown; not reddish.‡ Pores in late wood are thin-walled and angular in outline. **White Oak Group.**§ **White Oak,** *Quercus alba* L. (C, N) (Frontispiece)[31]; **Bur Oak,** *Q. macrocarpa* Michx. (C, N) (Figs. 13, 14, p. 42); **Overcup Oak,** *Q. lyrata* Walt. (C, S); **Post Oak,** *Q. minor* Sarg., or *Q. stellata* Wang. (C, A, S); **Oregon Oak,** *Q. garryana* Dougl. (P); **Chestnut** or **Rock Oak,** *Q. prinus* L (N, C)[32]; **Chinquapin** or **Yellow Chestnut Oak,** *Q. acuminata* (Michx.) Houba, or *Q. muhlenbergii* Eng. (C, S); **Swamp White Oak,** *Q. platanoides* (Lam.) Sudw., or *Q. bicolor* Willd. (N, C); **Cow Oak** or **Southern Swamp White Oak,** *Q. michuaxii* Nutt. (S, C).

b Late wood without distinct radial lines or patches, but with *tangential* or with *dotted* markings.

a¹ Pores in late wood very small, very numerous and arranged in conspicuous tangential or concentric bands or festoons, broken near early wood; usually producing wavy or zig-zag markings on tangential surface. Wood parenchyma not visible with lens.

a² Pores in early wood in few to several rows except sometimes in narrow growth rings; open.

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* In the white oaks of the South where the growth is rapid the transition from large to small pores is often nearly as gradual as in the red oaks. The pores in the summer wood are also larger and more distinct, but the fact that they are too numerous to count readily with a lens and have thin walls and angular outlines permits ready separation into the white oak class. A somewhat similar structure has been observed in *Quercus garryana*.

† In *Q. prinus* the pores are often open as in the black oak group.

‡ One finds occasional exceptions to this statement. Certain grades of white oak are locally known as "pink oak" on account of the color.

§ For evergreen and live oaks which are diffuse-porous, see p. 98.

a^3 Rays very distinct. Color yellowish or gray. No odor. Wood very coarse-textured; hard and heavy; sp. gr. .65–.80. Rays heterogeneous. Vessels with spirals; perforations simple; pits into ray cells half-bordered. **Hackberry,** *Celtis occidentalis* L. (C, N, S); **Sugarberry,** *C. mississippiensis* Bosc. (S).

b^3 Rays indistinct without lens. Color dark or chocolate-brown. Odor suggesting licorice sometimes noticed. Wood coarse-textured, wooly; straight-grained; hard and heavy; sp. gr. .65–.80. Rays homogeneous. Otherwise as in preceding. **Slippery** or **Red Elm,** *Ulmus pubescens* Walt., or *U. fulva* Michx. (C, N, S).

b^2 Pores in early wood mostly in a single row; occasionally more in wide growth rings. Rays indistinct without lens. Woods without odor. (Microscopic features as in preceding.) **Elm.**[33]

a^3 Pores in early wood rather large and distinct, mostly open, forming a continuous row (Plate III, Fig. 2), sometimes more than one row. Growth rings often very uneven and widely variable in thickness in different portions. Texture coarse and wooly. Color light brown to gray or nearly white. Wood very tough and difficult to split; moderately hard and heavy; sp. gr. .60–.75. **White Elm,** *U. americana* L. (C, N).[34]

b^3 Pores in early wood small to minute, mostly closed with tyloses in heartwood; larger pores few and rather widely separated in a band of small ones. Growth rings fairly even and uniform. Texture medium, not very wooly. Color light brown to pinkish. Woods hard to very hard; heavy and tough; sp gr. .70–.85.

a^4 Bands of small pores in late wood rather few, narrower than intervening spaces. Growth rings distinct. Wood straight-grained, fairly easy to split. **Rock** or **Hickory Elm,** *U. racemosa* Thom., or *U. thomasi* Sarg. (C, N).[35]

b[4] Bands of small pores in late wood numerous, wider than intervening spaces, often very wavy and branched. Growth rings not always distinct. Wood cross-grained, difficult to split. **Winged Elm,** *U. alata* Michx. (S, C); **Cedar Elm,** *U. crassifolia* Nutt. (S).

b[1] Pores in late wood variable in size from fairly large to minute, *clustered,* associated with parenchyma which often is confluent into tangential bands irregular and broken or more or less continuous in outer portion of wide rings.

a[2] Woods hard and heavy. Odorless. Color pronounced. Tyloses present or absent. Rays fine but distinct.

a[3] Tyloses present, light-colored; gum deposits absent or only occasional.

a[4] Wood decidedly variable in density but not horn-like; sp. gr. .55–.65. Color orange-yellow to yellowish-brown, not uniform; becoming russet-brown upon exposure. Pores only partially filled with tyloses. Band of pores in early wood varying from narrow to broad. Rays very conspicuous on radial surface. Small vessels with spirals; perforations simple; pits into ray cells simple or half-bordered. Rays heterogeneous. **Red Mulberry,** *Morus rubra* L, (C, S). (Plate V, Fig. 1); **White Mulberry,** *M. alba* L., (Int.).

b[4] Woods extremely hard, like horn; sp. gr. .77–.84. Color of freshly exposed wood mostly yellow (see below). All pores of heartwood completely filled with tyloses. Band of pores in early wood narrow. Rays not conspicuous on radial surface. Small vessels with spirals; perforations simple; pits into ray cells simple or half-bordered. Rays more or less heterogeneous, or with considerable irregularity in the shape of the cells.

a[5] Color of freshly exposed wood golden yellow, becoming orange-brown upon exposure to sunlight; usually with rather distinct reddish

streaks showing on longitudinal surface. Lustre high. Very small pin knots due to thorns common. Wood usually knotty and cross-grained, without worm holes. **Osage Orange,** *Toxylon pomiferum* Raf., or *Maclura aurantiaca* Nutt., (C, S). Plate III (Fig. 4).[36]

b⁵ Color varying from golden-yellow to brown, often greenish in young trees; usually uniform in same specimen; not striped with red. Lustre not so high as in preceding; wood mostly straighter-grained and freer from knots. Large worm holes common. **Black** or **Yellow Locust,** *Robinia pseudacacia* L. (C, A). Plate III (Fig. 3).[37]

b³ Tyloses absent or rare, not light-colored; dark-colored gum deposits present.

a⁴ Wood parenchyma conspicuous in numerous very irregular tangential bands which include the pores. Pores in late wood varying in size from minute to as large sometimes as in early wood; arrangement very irregular. Dark red gum deposits in vessels conspicuous, showing as dark wavy lines on tangential surface. Wood dull mahogany color; thin sapwood greenish yellow. Sp. gr. .77. Vessels without spirals; perforations simple; pits into ray cells half-bordered. Rays homogeneous. **Mesquite** or **Algaroba,** *Prosopis juliflora* (Schwartz) de C. (Rs).[38]

b⁴ Wood parenchyma mostly in patches about the pores in late wood, sometimes confluent in outer portion. Pores in outer portion of growth ring all very small; distribution fairly regular. Gum deposits usually inconspicuous. Sp. gr. .67–.70. Small vessels with spirals; perforations simple; pits into ray cells half-bordered. Rays mostly homogeneous.

a⁵ Pores in outer portion of late wood usually in groups of 5–20; individual pores visible under lens. Sapwood thin. Texture very

coarse. Color light cherry-red to reddish-brown. No small pin knots due to thorns. **Kentucky Coffee Tree,*** *Gymnocladus dioicus* Koch, or *G. canadensis* Lam. (C). (Plate III, Fig. 5.)

b[5] Pores in outer portion of late wood minute and usually in groups of 10–25; individual pores mostly invisible under lens. Sapwood thick. Texture moderately coarse. Color as above. Small pin knots due to thorns common. **Honey** or **Sweet Locust, Thorn Tree,** *Gleditsia triacanthos* L. (C, S). (Plate III, Fig. 6.)

b[2] Woods light and soft. Odor characteristic. Color not pronounced; mostly light brown. Tyloses present.

a[3] Rays fine but very distinct. Odor aromatic or spicy, usually pronounced. Color light orange-brown. Texture coarse. Sp. gr. about 50. Vessels without spirals; perforations simple; pits into ray cells half-bordered or simple. Rays heterogeneous (Fig. 3, A, p. 24). **Sassafras,** *Sassafras variifolium* (Salisb.) Ktze., or *S. sassafras* Karst. (S, C).[39]

b[3] Rays indistinct without lens. Odor mild, somewhat suggesting kerosene. Color light brown to chestnut, appearing somewhat bluish on ends of specimen. Texture rather fine. Wood lighter and softer than preceding; sp. gr. 40–45. Small vessels with spirals; all perforations simple; pits into ray cells half-bordered or simple. Rays heterogeneous. **Common Catalpa** or **Indian Bean,** *Catalpa bignoniodes* Walt., or *C. catalpa* (L.) Karst. (C, S); **Hardy Catalpa,** *C. speciosa* Ward. (C).[40]

b Pores in late wood few, solitary, or sub-divided radially into 2–4. Woods odorless and tasteless.†

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* This tree is sometimes called "mahogany" in eastern U. S.

† In this group of woods, which includes ash, persimmon and hickory, the sapwood, which is wide and white is more commonly employed than the heartwood for such purposes as implement stock (ash), tool handles and wheel stock (hickory), and shuttles (persimmon).

a[1] Wood parenchyma about pores in late wood and often extending wing-like from them; may become confluent into irregular tangential or concentric lines, especially near outer margin of wide growth rings; parenchyma also terminal. Pores in late wood all much smaller than those in early wood; the latter usually in a rather broad zone, 3–10 pores wide (rarely 1–2). Rays scarcely distinct without lens. Vessels without spirals; perforations simple; pits into ray cells half-bordered. Rays homogeneous. Terminal parenchyma thick-walled, abundantly and irregularly pitted. **Ash.***[41]

a[2] Pores in late wood rarely joined by wood parenchyma. Wood of medium hardness and strength.

a[3] Pores in late wood isolated, few, large; in early wood in very broad zone, often over one-half width of ring. Wood comparatively light and soft; sp. gr. .47. Color decidedly brown. Ray cells small. **Black or Brown Ash.** *F. nigra* Marsh. (C, N) (Plate V, Fig. 2).

b[3] Pores in late wood in radial groups of 2–5, and near outer margin of growth ring somewhat tangentially grouped; in early wood in zone of medium width, usually less than one-third of ring. Color light brown, often with reddish tinge. Wood moderately hard and strong. Sp. gr. .57. Ray cells large. **Oregon Ash,** *F. oregona* Nutt. (P).

b[2] Pores in late wood usually joined tangentially by wood parenchyma. Wood mostly very hard and strong, sp. gr. .63–.72. Color gray-brown, often with reddish tinge; sapwood white.

a[3] Pores in early wood in rather broad zone; numerous.

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* The specific determination of the ash woods is often difficult or impossible. Lumbermen usually recognize two kinds, namely, white and brown. These two unequal groups are readily distinguishable by their gross features. Some of the wood from southern swamp-grown trees has the structure of white ash but is very light, soft and brash; sp. gr. .38. It is sometimes called "punk ash" or "soft ash."

a[4] Lines of pores in late wood short, narrow, composed of few pores and considerable wood parenchyma; mostly near outer margin of growth ring; occasionally absent or very indistinct in narrow rings. **White Ash,** *Fraxinus americana* L. (C, N).[42]

b[4] Lines of pores in late wood long, narrow, prominent, composed of abundant wood parenchyma and inconspicuous pores; usually well distributed. **Blue Ash,** *F. quadrangulata* Michx. (C); **Red Ash,** *F. pennsylvanica* Marsh. (N).

b[3] Pores in early wood in rather narrow zone; fairly numerous. Lines of pores in late wood quite long and conspicuous; well distributed. **Green Ash,** *F. lanceolata* Borh. (C, N, S); **Pumpkin Ash,** *F. profunda* Bush. (C).

b[1] Wood parenchyma in numerous fine concentric lines independent of pores. Pores in late wood sometimes approaching in size those in early wood which are not abundant and usually arranged in a very irregular zone.

a[2] "Ripple marks" (see p. 39) plainly visible on tangential section; wavy; 60 to 80 per inch. Lines of wood parenchyma indistinct without lens; finer than the rays. Pores open. Color of heartwood of old trees dark brown to black, often streaked; sapwood white or gray. Wood very hard, heavy and strong; sp. gr. .79. Rays in horizontal seriation; fairly uniform in height; 1–2 (rarely 3) cells wide; cells large; heterogeneous. (Plate IV, Figs. 4, 5.) Vessels without spirals; perforations simple; pits into ray cells half-bordered. **Persimmon,** *Diospyros virginiana* L. (S, C).[43]

b[2] "Ripple marks" absent. Lines of wood parenchyma distinct as the rays; visible without lens. Pores partially or wholly closed with tyloses. Color of heartwood brown to reddish-brown; sapwood white, often with pinkish tinge and sometimes with dark reddish or rusty streaks. Rays irregularly disposed; not uniform in height or shape; 1–5 cells wide; cells small;

somewhat heterogeneous. (Plate IV, Fig. 3.) Vessels without spirals; perforations simple; pits into ray cells simple or half-bordered. **Hickory.***[44]

a[3] Wood very hard, heavy (sp. gr. .80–85), tough, strong, resilient. Wood fibres normally very thick-walled.† **Shagbark,** *Hicoria ovata* Brit. (C, N) (Plate IV, Fig. 3); **Big Shellbark,** *H. laciniosa* Sarg. (C); **Mocker Nut,** *H. alba* Brit. (C, N, S); **Pignut,** *H. glabra* Brit. (C, N, S).

b[3] Wood hard, heavy (sp. gr. .70–.75), brittle, fairly strong. Wood fibres comparatively thin-walled. **Pecan** *H. pecan* Brit. (S, C); **Nutmeg Hickory,** *H. myristicæformis* Brit. (S); **Bitternut,** *H. minima* Brit. (C, N, S); **Water Hickory,** *H. aquatica* Brit. (S).‡

B Diffuse-porous Woods. Pores fairly uniform in size and distribution throughout growth ring; occasionally more numerous and very often somewhat larger in early wood, but without forming a distinct ring or band.

a Pores variable from large to small, all or at least a portion of them readily visible to the unaided eye; comparatively few to numerous. Large vessels very distinct on longitudinal surface. Woods (except *Juglans cinerea*) moderately to extremely dense. (For **b,** see p. 99.)

a[1] All rays fine. Pores not in continuous radial lines. (For **b[1]**, see p. 98.)

a[2] Pores comparatively large in early wood, diminishing in size toward outer margin of growth ring; sometimes approaching ring-porous. Growth rings distinct. Vessels without spirals; perforations simple.

a[3] Wood parenchyma in numerous very fine concentric lines, independent of pores. Pores often in echelon arrangement; solitary or in radial groups

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* Specific distinction within the two groups of hickory woods is ordinarily not possible. The commercial names "red hickory" and "white hickory" refer to heartwood and sapwood, respectively. By "second-growth hickory" is meant wide-ringed wood and particularly the sapwood.

† Occasional exceptions to this general rule have been noted.

‡ *Hicoria aquatica* is so nearly diffuse-porous that it can usually be distinguished from the other species.

of 2–5; tyloses present. Color brown or purplish; never yellow. Rays fine, scarcely visible to unaided eye; 1–4 seriate, few to 30 cells high; mostly homogeneous. Pits between vessels and ray cells mostly simple. Growth rings terminated by narrow band of very thick-walled, flattened wood fibres. **Walnut.**[45]

a[4] Wood rather dense; sp. gr., .60–.70. Odor mild but characteristic. Color rich dark or chocolate-brown or purplish; sometimes variegated. Sapwood usually rather wide. Wood parenchyma with abundant crystals. Ray cells circular (tangential section). **Black Walnut,** *Juglans nigra* L. (C, A) (Plate IV, Fig. 6); **California Walnut,** *J. californica* Wats. (Ps).*

b[4] Wood light and soft; sp. gr. .35–.45. Odorless. Color light chestnut brown with darker zones. Sapwood very thin. Crystals absent. Ray cells small and compressed laterally. **Butternut, White Walnut,** *J. cinerea* L. (C, N).

b[3] Wood parenchyma about pores and, in late wood, joining groups of pores into irregular tangential lines. Pores irregularly disposed; solitary or in short radial groups. Tyloses absent. Color yellow. Wood dense; sp. gr. .60–.70. Rays fine, 1–6, mostly 3–4, cells wide and few to 40 cells high; mostly heterogeneous. Pits between vessels and ray cells half-bordered. Terminal fibres flattened but not thicker-walled than others. **Yellow-wood,** *Cladrastis lutea* (Michx. f.) Koch. (Sc).

b[2] Pores of approximately same size throughout growth ring; no tendency to become ring-porous. Growth rings not always distinct.

a[3] Wood parenchyma in tangential lines. "Ripple marks" present or absent. Pores resinous or gummy.

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* In the Yale collection is a board of *Juglans californica* in which the late wood is much lighter in color and the fibres much thinner-walled than in early wood.

a[4] Wood parenchyma conspicuous in few widely separated lines, apparently terminating growth rings; also about pores. "Ripple marks," when present, readily visible to unaided eye; about 50 per inch. Rays fine but distinct. Pores rather large, uniform in size and distribution, solitary or in radial groups of 2–3; often filled with dark red gum or with white deposits. Gum ducts occasionally present in peripheral row. Native wood hard and heavy; sp. gr. .73; color rich reddish brown; often highly figured.* Vessels without spirals; perforations simple; pits into ray cells half-bordered. Rays 1–4 cells wide, few to 20 or more cells high; heterogeneous. Wood fibres often finely septate; pits simple. **Mahogany,** *Swietenia mahagoni* Jacq. (T).[46]

b[4] Wood parenchyma in numerous fine, wavy lines. "Ripple marks" always present, uniform, invisible to unaided eye but distinct with lens; about 250 per inch. Rays very fine, indistinct. Pores not large but distinct, variable in size and distribution; solitary or in radial groups of 2–3. Color dark yellowish brown with greenish tinge, not uniform; becomes very dark and oily in old trees. Wood with interlocked or criss-cross grain; extremely dense; sp. gr. 1.14. Vessels without spirals; perforations simple; pits into ray cells small, half-bordered. Rays uniseriate; homogeneous; arranged in horizontal seriation. Wood fibres not septate; pits bordered. **Lignum-vitæ,** *Guaiacum sanctum* L. (T).

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* The true mahogany is native to a region extending from the extreme southern part of Florida to the West Indies, and along the Gulf Coast in Mexico from Tampico through Central America into the northern part of South America. There is a wide variation in the properties of the wood from different localities. That from Florida is like the hardest and heaviest of the West Indian grades. Mexican mahogany is the most variable in quality, some of it being light, soft and porous like Spanish cedar. There are many other woods which appear on the market as mahogany. See Mell's "True Mahogany," Bul. No. 474, U. S. Dept. Agr., 1917.

b[3] Wood parenchyma about pores; not in tangential lines. No "ripple marks." Pores not resinous or gummy.

a[4] Wood extremely dense; sp. gr. .83; fibres much interlaced. Alternate bands of wood varying in density and direction of fibre common, but growth rings not sharply defined. Pores conspicuous, irregularly distributed, often in diagonal chains which may be zig-zag; tyloses present. Rays very fine, indistinct. Vessels without spirals; perforations simple; pits into ray cells half-bordered or simple. Rays 1–2, occasionally more, cells wide and 1–25 cells high; somewhat heterogeneous. **Blue Gum,** *Eucalyptus globulus* Lab. (Int., Ps, T).[47]

b[4] Wood moderately dense, sp. gr. .65; grain variable from straight to wavy. Growth rings distinct, due to denser band of late wood. Pores rather small, mostly in radial groups of 2–6, fairly uniformly distributed; tyloses absent. Rays fine but distinct. Vessels without spirals; perforations simple; pits into ray cells half-bordered or simple. Rays 2–3 seriate, few to 25 cells high; mostly homogeneous. **California Laurel, Pepperwood,** *Umbellaria californica* (H. & A.) Nutt. (P).

b[1] Some of the rays usually very broad.* Pores somewhat variable in size but distinct; arranged in radial lines or bands between broad rays, extending across the growth ring and often continuous from one ring to another. Wood parenchyma commonly in concentric lines as well as about pores, frequently conspicuous. Wood very dense; sp. gr. .85–.95. Color light to dark brown, sometimes tinged with red. **Evergreen** and **Live Oak Group.**[48] *Quercus virginiana* Mill. (8); *Q. agrifolia* Nee. (Ps); *Q. chrysolepis* Liebm. (Ps.); *Q. wislizeni* A. de C. (Ps); **Tanbark Oak,** *Q. densiflora* H. & A., or *Pasania densiflora* Oerst. (P).[49]

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* It is not uncommon to find specimens of the woods of this group without broad rays, though in such cases there is a tendency to aggregation of the uniseriate rays.

b Pores small to minute,* often indistinct without lens (especially in dense woods), mostly very numerous and well distributed throughout growth ring. Vessels not conspicuous.

a[1] Woods dense to moderately so.† Rays variable from fine to broad. (For **b**[1], see p. 105.)

a[2] Pores in radial lines, not crowded laterally. Wood parenchyma in tangential lines.

a[3] Lines of wood parenchyma visible with lens on moist cross section. Pores in early wood visible to unaided eye. Wood dense, difficult to split. Vessels with spirals; perforations simple; pits into ray cells simple or nearly so. Wood fibres without spirals; pits bordered.

a[4] Rays all very fine, indistinct. Pores near periphery of growth ring minute and in groups which appear to the unaided eye as white dots. Growth rings sometimes sinuous; distinct. Color light brown or roseate. Sp. gr. .83. Rays heterogeneous in part. **Hop Hornbeam, Ironwood,** *Ostrya virginiana* Koch. (N, C) (Plate V, Fig. 6).

b[4] Some of the rays broad, aggregated. Pores in late wood sometimes as in preceding. Growth rings always sinuous; distinct or fairly so. Color yellowish white. Sp. gr. .73. Rays homogeneous. **Blue Beech, Water Beech,** or **Hornbeam,** *Carpinus caroliniana* Walt. (N, C).[50]

b[3] Lines of wood parenchyma not visible with lens. Pores not visible without hand lens; arranged in regular radial lines; no white dots. Rays distinct. Growth rings regular; rather indistinct. Wood moderately dense; sp. gr. .51–.66, average .58; fairly easy to split. Color chalky white, often

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* In a few woods of this group, particularly cottonwood and black willow, the pores, at least in early wood, are readily visible, but their abundance and the softness of the wood permit no confusion with the preceding group.

† A partial exception occurs in the case of *Nyssa,* some of the species of which produce light and soft woods.

bluish. Vessels with spirals; perforations scalariform with many bars; pits into ray cells half-bordered. Wood fibres with *spirals;* pits bordered. Rays heterogeneous; of two kinds: (1) Large (3–6 cells wide and up to 80 cells high) with all except marginal cells uniformly low; (2) fine (mostly uniseriate and few to many cells high) with all cells large.

Holly, *Ilex opaca* Ait. (S, C).

b² Pores not in radial lines although often in short radial groups; frequently crowded. Wood parenchyma sometimes in tangential lines but not visible with lens, except indistinctly in *Cornus* and occasionally in *Fagus*.

a³ Rays quite distinct to unaided eye. (For **b³**, see p. 103.)

a⁴ Conspicuously broad rays present; not aggregated.

a⁵ Rays nearly all broad, numerous; fairly regularly disposed and conspicuous on tangential surface; of deeper color than surrounding tissue, producing very distinct "silver grain" on radial or "quarter-sawed" surface. Wood parenchyma in irregular tangential rows but not visible with lens. Pores crowded. Woods fairly dense, usually cross-grained, splitting irregularly; sp. gr. .47–.57. Color light brown, often striped. Late wood thin, of lighter color than the early wood. Vessels without spirals; perforations mostly simple but often scalariform with few bars; bordered pits sometimes scalariform; pits into ray cells half-bordered. Rays homogeneous. Wood fibres with bordered pits. **Sycamore or Buttonball,** *Platanus occidentalis* L. (C, N, S); *P. racemosa* Nutt. (Ps); *P. wrightii* Wats. (Rs).[51]

b⁵ Only a portion of rays broad; variable, irregularly distributed; readily visible on tangential surface; intermediate rays very fine. Color of rays not pronounced, hence "silver grain" less conspicuous than in preceding

Wood parenchyma in tangential rows, occasionally visible with lens. Pores crowded. Wood dense; usually straight-grained; sp. gr. .63–.80, average .69. Color reddish brown to nearly white; uniform. Late wood rather thick, of darker color than the spring wood. Vessels without spirals; large perforations simple, small ones often scalariform; pits into ray cells half-bordered or simple. Rays heterogeneous. Wood fibres with bordered pits. **Beech,** *Fagus americana* Sw., or *F. grandifolia* Ehr. (C, N, S).[52]

b⁴ No conspicuously broad rays present.

a⁵ Wood parenchyma in somewhat broken tangential lines, faintly visible in part with lens on moist cross section. Rays light red or pink in color, very distinct. Color roseate to reddish-brown, sometimes with greenish hue. Wood very heavy, hard and tough. Vessels without spirals; perforations scalariform with many bars; bordered pits often scalariform; pits into ray cells half-bordered. Rays heterogeneous. Wood fibres with slit-like pits with distinct borders.

a⁶ Wood very dense, sp. gr. .76–.89, average .82. Rays 1–7 cells wide, few to 80 cells high. **Flowering Dogwood,** *Cornus florida* L. (N, C, S).

b⁶ Wood dense; sp. gr. .75. Rays 1–4 cells wide, few to 40 cells high. **(Western) Dogwood.** *Cornus nuttallii* Aud. (P.)

b⁵ Wood parenchyma not in tangential lines. Vessels with spirals; perforations simple; pits not scalariform; pits into ray cells half-bordered.

a⁶ Color rich reddish-brown or vinous. Rays on radial surface appear considerably lighter than background. Pores numerous, solitary or in groups, often radial, of 2–6; usually more abundant and larger in early wood but with gradual transition. Vessels

plugged at intervals with dark red gum. Gum ducts common. Wood variable in density; sp. gr. .48–.71, average .58. Rays mostly 3–5 cells wide, occasionally uniseriate, and few to 100 cells high; somewhat heterogeneous. Wood fibres with bordered pits. **Black Cherry,** *Prunus serotina* Ehrh. (C, N, S).

b[6] Color variable from very light to decidedly reddish. Rays on radial surface appear considerably darker than background; variable in size. Pores not crowded, fairly evenly distributed; solitary or in radial groups of 2–3; fairly uniform in size throughout growth ring. Grain often curly, "landscape," or "birds-eye." Rays homogeneous. Wood fibres with bordered to simple pits. **Maple.***[53]

a[7] Part of the rays comparatively large, broader than the pores, conspicuous. Pith flecks rare. Growth rings very distinct on account of deeper-colored late wood. Wood dense; ave. sp. gr. .69. Rays 5–7 cells wide with intermediate rays uniseriate. **Hard, Sugar,** or **Rock Maple,** *Acer saccharum Marsh.* (N, C.)[54]; **Black Maple,** *A. nigrum* Michx. (N, C).

b[7] With less variation in the size of the rays, the large ones not so broad as the pores; low, inconspicuous. Growth rings often indistinct. Woods variable from soft to moderately hard. Uniseriate rays few.

a[8] Color deep and rich. Pith flecks uncommon. Sp. gr. .49. **Oregon Maple,** A. *macrophyllum*. (P).

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* Boxelder or ash-leaved maple, *Acer negundo* L., or *Negundo aceroides* Moench. (N, C, S, R), and its varietal form, *californicum* (T. & G.) Sarg. (Ps), produce rather light (sp. gr. .43), soft woods, cream-colored or yellowish white. The pores are small and numerous; often in radial groups of 2–6. Rays are without color.

b[8] Color pale, often with greenish tinge. Pith flecks very common, often abundant. Sp. gr. .62. **Soft** or **Red Maple,** *A. rubrum* L. (N, C, S); **Silver Maple,** *A. saccharinum* L. (N, C, S).

b[3] Rays indistinct without lens.

a[4] Wood mostly straight-grained, easy to split. Growth rings usually distinct. Wood parenchyma scattered, sometimes in broken tangential lines in outer late wood and in a single terminal layer usually visible as a faint white line. Vessels without spirals; densely pitted with extremely small bordered pits with slit-like openings; perforations scalariform; pits into ray cells half-bordered. Rays 1–5 cells wide; homogeneous. Wood fibres with bordered pits. **Birch.**[55]

a[5] Wood mostly heavy, hard and strong. Color brown tinged with red, sometimes deeply reddish; often figured. Pith flecks rare.

a[6] Specific gravity .69–.82, average .76. Rays widest of genus, bluntly tapering; cells round (tangential section). **Sweet, Black** or **Cherry Birch,** *Betula lenta* L. (S, C, N).*

b[6] Specific gravity .58–.72, average .66. Rays narrower, cells flattened laterally (tangential section). **Yellow Birch,** *B. lutea* Michx. f. (N, C).

b[5] Wood considerably less dense than in preceding group; sp. gr. average .58–.60. Colorless or light brown. Pith flecks common.

a[6] Pores rather large, readily visible to unaided eye. Wood rather coarse-textured; sometimes cross-grained. Sp. gr. .55–.60. **River** or **Red† Birch,** *B. nigra* L. (S, C, N).

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* The woods of *Betula lenta* and *B. lutea* appear on the market together without distinction as to species, and have identical uses. The former is somewhat harder and stronger as a rule.

† The names "red birch" and "white birch" are often used commercially to designate the heartwood and sapwood, respectively, of *Betula lenta* and *B. lutea.*

b⁶ Pores very small, indistinct to unaided eye. Woods fine-textured and straight-grained; lighter-colored than preceding. Sp. gr. .46–.64. **Paper, White** * or **Canoe Birch,** *B. papyrifera* Marsh. (N, Rn, Pn)[56]; **Gray Birch,** *B. populifolia* Marsh. (N).

b⁴ Woods mostly cross-grained, tough to split. Growth rings usually indistinct. Wood parenchyma scattered, not in tangential lines or terminal.

a⁵ Wood very dense; sp. gr. about .75. Color reddish-brown or roseate; sapwood yellowish.† Pores minute, well distributed, very numerous. Vessels without spirals; bordered pits round; perforations *simple;* pits into ray cells half-bordered. Rays 3–4 cells wide; homogeneous. Wood fibres with numerous large bordered pits. **Apple,** *Pyrus malus* L. (Int.)[57]

b⁵ Woods variable in density. The denser ones colorless or light brown. Grain more interlocked than preceding. Rays 1–5 cells wide; heterogeneous. Vessels mostly without spirals; scalariform bordered pits common; perforations *scalariform* with many bars. Pits in wood fibres not conspicuous.

a⁶ Color reddish-brown, often with irregular dark streaks producing "watered" effect on smooth longitudinal surface; sapwood often variegated. Lustre rather dull. Pores minute, abundant, uniformly distributed; tyloses present. Gum ducts occasionally present in peripheral row. Wood moderately hard to rather soft; inclined to warp; sp. gr. .50–.60. Vessels without spirals except indistinctly on overlapping ends of seg-

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* The names "red birch" and "white birch" are often used commercially to designate the heartwood and sapwood, respectively, of *Betula lenta* or *B. lutea*.

† In the use of applewood for handles it is customary to steam the sapwood. This treatment produces a rich uniform color resembling that of black cherry.

ments; pits into ray cells simple or half-bordered; no "resin plates." Rays 1–2 cells wide, few to 30 cells high; containing dark gum. **Red or Sweet Gum, Gumwood, "Hazel,"** *Liquidambar styraciflua* L. (S, C). (Plate VI, Fig. 1.)[58]

b[6] Color brown to nearly white, fairly uniform. Lustre high. Pores variable in size and abundance in different species; tyloses absent. Gum ducts absent. Light-colored transverse "resin plates" usually present in vessels and fibres of heartwood.* Vessels wholly without spirals.

a[7] Wood usually rather dense, tough and strong; sp. gr. .56–.75, average .64. Pores minute, not crowded. **Black or Sour Gum, Pepperidge,** *Nyssa sylvatica* Marsh. (C, N, S).

b[7] Wood rather light and soft; tough but not strong; sp. gr. .40–.56, average about .50. Pores small, crowded. **Tupelo, Bay Poplar,** *N. aquatica* L. (S, C); *N. biflora* Walt. (S).[59]

b[1] Woods mostly light and soft. Rays fine.†

a[2] Rays distinct to unaided eye.

a[3] Growth rings terminated by distinct light-colored line of parenchyma; no parenchyma lines within growth ring. No "ripple marks" on wood. Vessels as below; tyloses few, thin-walled, inconspicuous. Woods soft but firm, occasional specimens rather hard; straight-grained, as a rule. Rays fairly uniform for each species; heterogeneous (marginal cells square or upright); cell walls very thick, abundantly and irregularly pitted; pits into vessels often in groups with common border. Terminal parenchyma in 2–3 rows; cells thick-walled and very irregularly pitted (tangential section).

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* See author's "Significance of Resinous Tracheids," Botanical Gazette, 66 : 1 : 61–67, (July 1918).

† A partial exception occurs in *Alnus* where aggregate rays are often found.

a[4] Pores rarely in radial groups. Color widely variable, depending upon age of tree and locality of growth, from clear yellow to green, brown or purplish; sapwood often variegated or striped, light gray or nearly white. Curly and mottled grain not uncommon. Sp. gr. .38–.48, average .42. Vessels with *round* or *elliptical* bordered pits in rows, sometimes scalariform in part; without spirals; perforations scalariform with few bars. Rays mostly 3-seriate, few to 60, mostly 20–40, cells high. **Poplar, Yellow Poplar, Tulip-tree, Whitewood.** *Liriodendron tulipifera* L. (C, N). (Plate VI, Figs. 2, 4).[60]

b[4] Pores often in radial groups of 3–8. Vessels with *scalariform* bordered pits (Plate VI, Fig. 3); spirals indistinct.

a[5] Color mostly yellow or greenish; often closely resembling *Liriodendron.* Sp. gr. .42–.54, average .47. Vessel perforations usually *simple.* Rays homogeneous; mostly 2-seriate and 10–15 cells high. **Cucumber Tree,** *Magnolia acuminata* L. (C, A).

b[5] Color light brown. Sp. gr. about .50. Vessel perforations *scalariform* with few bars. Rays heterogeneous; 2–4 cells wide, mostly 50–100 cells high. **White or Sweet Bay,** *M. glauca* L. (S).

b[3] Wood parenchyma not visible with lens. Wood elements, except rays, in storied arrangement, producing somewhat indistinct "ripple marks" on tangential surface; 55–60 per inch. Wood light, soft, compact, moderately strong; sp. gr. .38–.52, mostly between .40–.45. Color light brown to creamy white. Rays of two general sizes: (1) uniseriate and 10–15 cells high; (2) 3–5 cells wide and 50–100 cells high; mostly homogeneous. Vessels with spirals; tyloses absent; perforations simple; bordered pits not scalariform; pits into ray cells small, half-bordered. Wood parenchyma in numerous fine tangential lines. **Basswood, Lin,** *Tilia americana* L. (N, C); *T. pubescens* Ait. (S, C); *T. heterophylla* Vent. (A, C, S).[61]

b^2 Rays indistinct to unaided eye and often with lens, except for occasional aggregate rays in *Alnus oregona*.

a^3 Rays fairly distinct with lens.

a^4 Wood of very fine texture. Pores minute, invisible without lens, very uniformly distributed. Color pale yellow to nearly white. Lustrous. Growth rings terminated by fine line of wood parenchyma. Pith flecks absent. Wood light, soft, compact, tough, often with curly or interlocked grain; sp. gr. .42–.50. Vessels with spirals; perforations simple; pits into ray cells half-bordered; often grouped. (Fig. 3, C, p. 24). Rays all uniseriate; heterogeneous.

a^5 "Ripple marks" distinct on tangential surface; fairly regular; 65–70 per inch; all elements storied. **Yellow Buckeye,** *Æsculus octandra* Marsh. (C).[62]

b^5 "Ripple marks" absent or local; very irregular. **Ohio Buckeye,** *A. glabra* Willd. (C). (Plate VI, Figs. 5, 6); **California Buckeye,** *A. californica* Nutt, (Ps).

b^4 Wood of only moderately fine texture. Pores barely visible to unaided eye; somewhat larger and more numerous in early wood; often in short radial groups. Color light brown tinged with red; surface of freshly cut sapwood soon stained greenish-brown upon exposure. Lustre dull. Pith flecks common. "Ripple marks" absent except possibly over small areas. Wood light, firm, moderately strong; sp. gr. about .48. Growth rings not terminated by parenchyma. Broad rays occasionally present, being aggregates of small rays. (Plate V, Figs. 3, 4). Ordinary rays 1–2 cells wide; homogeneous. Vessels without spirals; perforations scalariform, few to many bars; pits into ray cells half-bordered. Wood parenchyma scanty, diffuse. **Red Alder,** *Alnus oregona* Nutt., or *A. rubra* Bong. (P).[63]

b^3 Rays indistinct even under lens.

a[4] Color of wood reddish-brown, usually variable. Lustre dull. Texture coarse. Pores very abundant, readily visible to unaided eye; smaller in late wood and sometimes in irregular tangential arrangement in wide growth rings. Wood light and soft but fairly tough; sp. gr. .41–.47. Wood parenchyma terminal in 1–2 rows, usually invisible with lens. Vessels without spirals; perforations simple; pits into ray cells simple. Rays uniseriate; heterogeneous. **Black Willow, "Brown Cottonwood,"** *Salix nigra* Marsh. (C, N, S, Rs, Ps).[64]

b[4] Color pale brown, grayish or white. Woods very light and soft. Growth ring terminated by fine light-colored line of parenchyma, more or less distinct. Vessels without spirals; perforations simple; pits into ray cells simple. Rays uniseriate; homogeneous.

a[5] Texture rather coarse and wooly. Lustre dull. Pores abundant, visible without lens, smaller in late wood and sometimes in irregular tangential arrangement in wide growth rings. Sp. gr. .32–.48, average about .40. **Poplar, Cottonwood,** *Populus deltoides* Marsh. (N, C, S, R)[65]; *P. heterophylla* L. (S, C); *P. trichocarpa* T. J. G. (P).

b[5] Texture very fine and silky. Lustre high. Pores abundant, usually invisible without lens; fairly uniform in size and arrangement. Sp. gr. .36–51, mostly .40–.45. **Aspen, Poplar, Popple,** *P. tremuloides* Michx. (N, C, R, P); *P. grandidentata* Michx. (N, C).[66]

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APPENDIX

THE WOODS OF THE UNITED STATES

Wood of economic importance is obtained from certain representatives of the highest sub-division of the plant world — the Spermatophytes or true flowering and seed-bearing plants. Botanists separate this large group, chiefly on the basis of floral and fruit characters, into two classes, viz., the Gymnosperms and the Angiosperms.

The Gymnosperms are all woody plants, either trees or shrubs. Of the fifteen genera indigenous to the United States, two (*Taxus* and *Tumion* or *Torreya*) belong to the Taxaceæ or yew family and are of little or no commercial importance. The other thirteen belong to the Coniferæ or true cone-bearers.

The woods of the Coniferæ, commonly known as coniferous woods or softwoods, are esteemed for structural purposes because they combine a high degree of strength and stiffness with comparatively light weight and ease of manipulation. They are separable into (*a*) the pine-like and (*b*) the cedar-like. The first includes the pines (*Pinus*), Douglas fir (*Pseudotsuga*), spruces (*Picea*), larches (*Larix*), true firs (*Abies*), and the hemlocks (*Tsuga*). The second group embraces the junipers (*Juniperus*), various cedars (*Chamæcyparis*, *Thuya*, *Libocedrus*), the cypresses (*Cupressus* and *Taxodium*), and the sequoias (*Sequoia*). The cedar-like woods are characterized by their resistance to decay and also, with the exception of *Taxodium* and *Sequoia*, by their fragrant scent.

The Angiosperms are very abundantly represented in the flora of this country and include a large proportion of herbaceous forms. Two sub-classes are recognized, viz., the Monocotyledons and the Dicotyledons, referring to the number of cotyledons or seed-leaves of the embryo. There are also fundamental differences in their stem structures.

Monocotyledonous stems are mostly unbranched and the wood is confined to isolated strands disposed irregularly in a mass of softer tissue, becoming more and more compact toward the surface. In general, there are lacking certain important features which characterize the stems of both Gymnosperms and Dicotyledons,

viz., (*a*) a distinct central core of pith, (*b*) a covering of bark, and between these two (*c*) a fairly uniform mass of wood which increases in thickness by the addition of periodic layers on the outside.

Some well-known representatives of the Monocotyledons are the grasses (including maize, wheat, many other cereals, the bamboos, etc.), the sedges, lilies, bananas, rattans, palms, and yuccas. The woody types are confined chiefly to tropical and sub-tropical regions where they are extensively used but not in the form of lumber. There are seven kinds of palms and nine kinds of yuccas of tree size native to the United States. They are used to some extent locally but as a commercial source of wood are wholly negligible.

As stated on p. 7 there are, according to Sargent's "Manual of the Trees of North America," 57 families and 147 genera of Dicotyledons with representatives of tree size in this country. The total number of species described is 607. Various others have been introduced, mostly for decorative purposes but also to a small extent for forest planting, and a few have become naturalized, but only in rare instances do their woods contribute to our commercial supply. Sudworth's "Check List"* enumerates 495 trees, including a few which have become thoroughly naturalized. This discrepancy is accounted for mostly by the large number of species of *Cratægus*, 132 in all, described by Sargent as against 25 listed by Sudworth. Not a single representative of this genus is of commercial importance for its wood, and of the 34 species belonging to the other genera of the Rosaceæ only one, *Prunus serotina*, is a source of valuable lumber. One willow out of 21 species, about 20 oaks out of a total of 47, and about a dozen pines out of the 34 native to this country are commercially valuable. In the Government reports on lumber production only 30 kinds are considered of sufficient importance to justify separate tabulation, while about 20 are grouped under the single heading of "minor species."

The following list includes the most important families and genera of the Dicotyledons. Included in it are seven families which are really of secondary importance so far as the amount of the wood produced is concerned. These are, Aquifoliaceæ, Bignoniaceæ, Ebenaceæ, Hippocastanaceæ, Lauraceæ, Meliaceæ, and Moraceæ.

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* Sudworth, George B.: Check List of the Forest Trees of the United States, Their Names and Ranges. Bul. No. 17, U. S. Division of Forestry, Washington, D. C., 1898.

TABLE V

Important Families and Genera of Dicotyledons in the United States

Aceraceæ
Acer (maple)
Aquifoliaceæ
Ilex (holly)
Betulaceæ
Alnus (alder)
Betula (birch)
Bignoniaceæ
Catalpa (catalpa)
Cornaceæ
Cornus (dogwood)
Nyssa (tupelo)
Ebenaceæ
Diospyros (persimmon)
Fagaceæ
Castanea (chestnut)
Castanopsis (chinquapin)
Fagus (beech)
Quercus (oak)
Hamamelidaceæ
Liquidamabar (red gum)
Hippocastanaceæ
Æsculus (buckeye)
Juglandaceæ
Hicoria (hickory)
Juglans (walnut)
Lauraceæ
Sassafras (sassafras)
Leguminosæ
Gleditsia (honey locust)
Gymnocladus (Ky. coffee-tree)
Robinia (black locust)
Prosopis (mesquite)
Magnoliaceæ
Liriodendron (tulip-tree)
Magnolia (magnolia; cucumber)
Meliaceæ
Swietenia (mahogany)
Moraceæ
Morus (mulberry)
Toxylon (Osage orange)
Oleaceæ
Fraxinus (ash)
Platanaceæ
Platanus (sycamore)
Rosaceæ
Prunus (black cherry)
Salicaceæ
Populus (poplar; cottonwood)
Salix (willow)
Tiliaceæ
Tilia (basswood)
Ulmaceæ
Celtis (hackberry)
Ulmus (elm)

TABLE VI

Numerical Conspectus of the Trees of the United States

Class		Number of Families		Number of Genera		Number of Species		Number of Economic Species which can be identified from the Wood alone
		Total	Economic	Total	Economic	Total	Economic	
Gymnosperms		2	1	15	12	69	37	25–30
Angiosperms	Monocotyledons	2	0	8	0	19	0	
	Dicotyledons	57	22	147	40	519	100	55–65
Totals		61	23	170	52	607	137	80–95

WOOD STRUCTURE

Wood is a fibrous structure composed of cells which are for the most part greatly elongated in a vertical or axial direction. Longitudinal surfaces accordingly show the fibrous nature of wood to the best advantage, while the cross section appears under the microscope more or less like a fine honey-comb. Some wood cells are large enough to be readily seen, others are at the limit of vision and require a hand lens for distinctness, and a much larger number are not individually visible without considerable magnification.

All wood cells when first formed contain living protoplasm but a large proportion of them apparently lose it very early. Such cells provide channels for sap-flow from root to leaf, lend strength and rigidity to the stem, and in some instances supply spaces for storage of excess food and reservoirs for waste products. Since these functions are in part physiological it seems unlikely that the protoplasm has entirely disappeared from the elements concerned, even if its presence cannot be directly demonstrated, since cells without living protoplasm can only function mechanically.

The wood cells which obviously retain living protoplasm throughout their functional period may be referred to as food cells (parenchyma) since they are primarily concerned with the distribution and storage of plant food. This food is elaborated in the leaves (and other green tissues) and is transported along the stem chiefly through certain channels (sieve-tubes of the phlœm) in the inner bark. The cells (ray parenchyma) which divert portions of the food current into the wood are typically elongated in a horizontal or radial direction, while those (wood parenchyma) which distribute it vertically in the stem are axially elongated. Plant food assumes various forms, the principal ones being starch, sugars and fats; the change from one form to another is brought about by the action of certain ferments or enzymes.

Structurally, a wood cell consists of a *cell wall* of ligno-cellulose, inclosing a *lumen* or *cavity* (with or without visible contents), and completely surrounded by a pectic layer called the *middle lamella.* The lignified wall provides a strong and rigid framework. The middle lamella limits the individual cells and cements them firmly together to form the wood-mass. The cavity serves various purposes such as the transportation of food and water, aëration, storage, etc., and must accordingly be in communication with the

cavities of adjacent cells and in some instances with intercellular spaces also.

Where the cell walls are thin enough there is no need for special provision for intercommunication. The process of thickening reduces the permeability of the walls and makes necessary the leaving of thin or unthickened spots called *pits*. Were the wall uniformly thickened throughout, the lumen would become isolated and the function of the cell would be reduced to that of reinforcement only, a condition approximated in the libriform fibres of certain woods such as *Toxylon* and *Robinia*. At the other extreme, there are elements (vessels) concerned with the rapid conduction of water which are composed of vertical series of cells whose pits at the ends have given place to true openings or *perforations*. The only fundamental difference between a perforation and a pit is that in a pit the middle lamella, somewhat modified, forms a limiting or pit membrane. The presence of minute perforations in this membrane can be demonstrated by passing finely divided solid particles through it.

Some cells have simple pits while others appear under the compound microscope to have a more or less distinct border. This border is due to the wall overhanging the margin of the pit membrane. Pits between food-cells are simple while those between water-carriers are bordered. Where the two types of cells are in communication the half of the pit in the food-cell is always simple and the corresponding portion in the other may be either simple or bordered. In the latter case the pit is structurally half-bordered, though in surface view it may not be distinguishable from one that is bordered on both sides. Pits exhibit a wide range of variation in size, shape and arrangement, and possess high value for purposes of classification of woods. (For further details see pp. 31–35.)

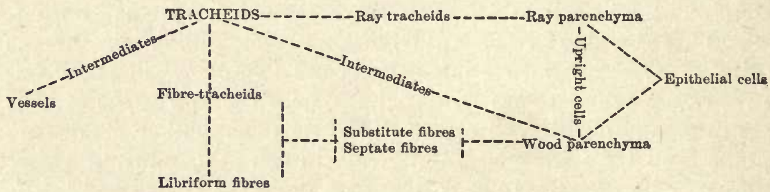
CLASSIFICATION OF THE ELEMENTS OF SECONDARY WOOD

On p. 13 the cellular elements of wood are referred to three principal types, viz., vascular, fibrous and parenchymatous. Some authors prefer the following classification: (*a*) *vessels* (cell-fusions serving for the conduction of water); (*b*) *parenchyma* (food cells which conduct and store carbohydrates); (*c*) *prosenchyma* (cells serving chiefly to give mechanical support but often participating in functions of the other groups). The prosenchyma in-

cludes all of the vertical elements of the wood except vessels and parenchyma, namely, libriform fibres, septate fibres, intermediate or substitute fibres, fibre-tracheids, and tracheids.

Libriform fibres are the cells referred to on p. 18 as typical wood fibres. Fibre-tracheids are fibrous cells with distinctly bordered pits and are intermediate between libriform fibres and vessel-like tracheids; they do not occur in Gymnosperms though the tracheids of the late wood might with some justification be so-called.

The following diagram shows the relationships of the various elements. In this the tracheid appears as the dominant element. Vessels are composed of segments which were originally tracheids before fusion; intermediate forms occur. Fibre-tracheids and libriform fibres may be considered as modifications of the tracheid in which the mechanical function of strength is emphasized at the expense of water conduction. Intermediate forms between these cells and parenchyma are shown in the diagram which were not brought out in the other classifications. Epithelial cells of resin ducts are shown as specialized forms of parenchyma.



VESSELS

Vessels are compound elements; they are composed of *segments* which have become fused at the ends (and sometimes at the sides as well) into vertical series. Each segment normally arises from a single cambial cell and when first formed is completely inclosed by the middle lamella and is morphologically a tracheid. After fusion the cells function, not as a series of individuals, but as a continuous tube.

The segments may abut on each other squarely at the ends or overlap more or less. Both forms may occur in the same vessel, though decidedly elongated tips are characteristic of certain species. Such tips are usually provided with bordered pits and in some instances exhibit spiral thickenings even though the body of

the segment does not. Sometimes segments are fused through their lateral walls, or the end of one segment may be joined to the lateral wall of another, but such forms are to be considered exceptional.

The plane of contact between segments may be: (*a*) horizontal or transverse, that is, at right angles to the axis of the vessel; (*b*) oblique or inclined, almost always facing the ray; (*c*) vertical or longitudinal. The last may be considered an extreme form of the oblique unless it occurs where segments are fused through their lateral walls.

VESSEL PERFORATIONS

The opening from one segment into another is called the *vessel perforation*. The various types and modifications of vessel perforations supply features highly important for diagnostic purposes. The two principal forms are : (*a*) the *simple* and (*b*) the *scalariform*. Insofar as our commercial woods are concerned knowledge of these two types is sufficient. There are various other forms, however, though most of them are modifications or malformations of the two principal types. The reticulate form is not uncommon, especially in the Rosaceæ, and tendency to it is seen in the branching and anastomosing bars in almost all woods with scalariform perforations. In *Rosa* sp. the author has observed in a single section, simple (predominating), scalariform, reticulate, pit-perforate, and various composite perforations.

The following classification shows the range of variation in perforations, though there are innumerable forms of the composite. A few instances, mostly exotics, are cited as illustrations of the rarer kinds.

TYPES OF VESSEL PERFORATIONS

SIMPLE: (Single opening, circular, elliptical or elongated-elliptical.)

SCALARIFORM: (Openings slit-like or elongated between cross bars.)

- Bars transverse (Common form).
- Bars vertical (Very rare. In certain Compositæ and *Axyris amarantoides*).

RETICULATE: (Irregular openings as meshes between anastomosing bars.)

MULTIPERFORATE: (Plural circular or elliptical openings.)
  Few comparatively large openings (*Ephedra;* occasionally in *Vaccinium uliginosum* and *Leitneria floridana*).
  Numerous small openings (*Canella alba; Menziesia ferruginea*).
PIT-PERFORATE: (Not readily distinguishable from pits.) (Occasionally in *Meisteria cernua, Lithospermum fruiticosum, Cheirodendron* sp., *Rosa* sp.)
COMPOSITE: (Mostly malformations occasionally met with.)
  Simple-scalariform: (*Quillaja*, certain Bignoniaceæ, etc.)
  Simple-reticulate: (*Sorbus aucuparia, Sidonia vulgaris, Rosa* sp., *Cheirodendron gaudichaudii*, etc.)
  Scalariform-reticulate: (*Didymopanax morototoni.*)

Simple perforations characterize a large majority of our native woods. Where the plane of perforation is transverse or only slightly inclined the simple type is almost invariably found. Where the perforation is inclined it may be either simple or scalariform. The opening may be circular, elliptical, or oblong-elliptical. The elliptical form prevails where the plane of perforation is oblique. Usually the end walls are not completely removed in the formation of a simple perforation and the border remaining is called the *annular ridge.* This ridge may vary in width from very narrow to fairly broad.

There are a number of families in which all of the investigated genera have exclusively simple perforations. Prominent among these are the following: Aceraceæ, Bignoniaceæ, Ebenaceæ, Juglandaceæ, Leguminosæ, Moraceæ, Salicaceæ, and Tiliaceæ. There are a number of others in which the simple type predominates but where scalariform perforations are occasionally or rarely found in the secondary wood or where, from the nature of the perforations in the primary wood, they are to be expected. Important examples are the Betulaceæ, Fagaceæ and Rosaceæ. Both simple and scalariform perforations may occur commonly side by side in the secondary wood, as for example, in *Fagus* and *Platanus.* Occasionally a segment is found in which the perforation at one end is simple and at the other scalariform. Table VII includes nearly all of the genera of native trees having vessel perforations exclusively or predominately simple. The representatives of the families marked with (*) exhibit some tendency toward the formation of the scalariform type. The more important genera are shown in italics.

TABLE VII

Indigenous Woods with Vessel Perforations Exclusively or Predominantly Simple

- Aceraceæ
  - *Acer*
- Anacardiaceæ
  - Cotinus
  - Rhus
- Anonaceæ
  - Anona
  - Asimina
- Betulaceæ *
  - *Carpinus*
  - *Ostrya*
- Bignoniaceæ
  - *Catalpa*
  - Chilopsis
  - Crescentia
- Boraginaceæ
  - Ehretia
- Burseraceæ
  - Bursera
- Cactaceæ
  - Cereus
  - Opuntia
- Capparidaceæ
  - Capparis
- Caprifoliaceæ*
  - Sambucus
- Combretaceæ
  - Buceras
  - Conocarpus
  - Laguncularia
- Ebenaceæ
  - *Diospyros*
- Ericaceæ *
  - Arbutus
  - Arctostaphylos
- Euphorbiaceæ *
  - Drypetes
- Fagaceæ *
  - *Castanea*
  - *Castanopsis*
  - *Fagus*
  - *Quercus*
- Hippocastanaceæ
  - *Æsculus*
- Juglandaceæ
  - *Hicoria*
  - *Juglans*
- Lauraceæ *
  - Ocotea
  - Persea
  - *Sassafras*
  - *Umbellaria*
- Leguminosæ
  - Acacia
  - Cercidium
  - Cercis
  - *Cladrastis*
  - Dalea
  - Eysenhardtia
  - *Gleditsia*
  - *Gymnocladus*
  - Icthyomethia
  - Leucæna
  - Lysiloma
  - Olneya
  - Parkinsonia
  - *Prosopis*
  - *Robinia*
  - Sophora
  - Zygia
- Leitneriaceæ
  - Leitneria
- Magnoliaceæ *
  - *Magnolia acuminata*
- Meliaceæ
  - *Swietenia*
- Moraceæ
  - *Morus*
  - *Toxylon*
- Oleaceæ
  - Chionanthus
  - *Fraxinus*
  - Osmanthus
- Polygonaceæ
  - Coccolobis
- Rhamnaceæ
  - Ceanothus
  - Colubrina
  - Condalia
  - Krugiodendron
  - Reynosia
- Rosaceæ *
  - Amelanchier
  - Cercocarpus
  - Chrysobalanus
  - Cratægus
  - Heteromeles
  - Lyonothamnus
  - Malus
  - *Prunus*
  - Sorbus
  - Vauquelinia
- Rubiaceæ
  - Pinckneya
- Rutaceæ
  - Amyris
  - Fagara
  - Helietta
  - Ptelea
- Salicaceæ
  - *Populus*
  - *Salix*
- Sapindaceæ
  - Exothea
  - Hypelate
  - Sapindus
  - Ungnaria
- Sapotaceæ
  - Bumelia
  - Chrysophyllum
  - Sideroxylon
- Simarubaceæ
  - Ailanthus (Nat.)
  - Simaruba
- Tiliaceæ
  - *Tilia*
- Ulmaceæ *
  - *Celtis*
  - Planera
  - *Ulmus*
- Zygophyllaceæ
  - *Guaiacum*

* With some tendency to scalariform, particularly in the region of primary wood.

Scalariform perforations look like a grid-iron or grating with an elliptical or elongated-elliptical contour. The bars, with very rare exceptions, are arranged horizontally or transversely. As the plane is almost invariably strongly oblique and facing the ray, the structure is seen to much better advantage in radial sections than in the transverse and tangential. Macerated material is better still since a portion of the tilted plate is likely to be cut off in sectioning. Bars may also be seen in the lumina of some of the vessels in the transverse section, especially if the section is rather thick.

The number of bars in a perforation varies from very few to

more than 100. Within the same species, however, the variation is within narrower limits, though the number is never constant. In *Magnolia* and *Liriodendron*, for example, the number of bars is usually less than 15 and the spaces are wide, while in *Ilex*, *Nyssa*, and *Liquidambar* the bars are much more numerous and are closely spaced.

In the following table are listed the genera of native woods in which the vessel perforations are exclusively scalariform. In a few cases, perhaps, simple perforations will occasionally be found in association with the predominant type. The list is believed to be complete so far as the trees are concerned but not for the shrubs. Eight of the genera yield wood of commercial importance. It will be noted that no ring-porous wood is included. Scalariform perforations are never found in large vessels, such for instance as are individually distinct to the unaided eye, presumably because the presence of gratings would interfere with the function of large vessels, namely, the rapid conduction of water in quantity. Solereder calls attention to "the striking fact that the occurrence of scalariform perforations in the vessel often goes hand in hand with small lumina and the presence of bordered pits on the prosenchyma." (Systematic Anatomy of the Dicotyledons, p. 1138.)

TABLE VIII

INDIGENOUS WOODS WITH VESSEL PERFORATIONS EXCLUSIVELY SCALARIFORM

AQUIFOLIACEÆ	MAGNOLIACEÆ
Ilex	*Liriodendron*
BETULACEÆ	*Magnolia* (mostly)
Betula	MYRICACEÆ
Alnus	Myrica*
Corylus	MYRTACEÆ
CAPRIFOLIACEÆ	Eugenia
Viburnum	RHIZOPHORACEÆ
CORNACEÆ	Rhizophora
Cornus	SAXIFRAGACEÆ
Nyssa	Philadelphus
CYRILLACEÆ	Hydrangea
Cyrilla	Ribes
Cliftonia	SYMPLOCACEÆ
ERICACEÆ	Symplocos
Rhododendron	STAPHYLEACEÆ
Kalmia	Staphylea
Vaccinium	STYRACEÆ
Andromeda	Mohrodendron
HAMAMELIDACEÆ	THEACEÆ
Liquidambar	Gordonia
Hamamelis	

* Some simple perforations present in *Myrica californica.*

VESSEL MARKINGS: SPIRALS AND PITS

The first-formed elements of the primary wood, those nearest the pith, have walls characteristically marked with annular and spiral thickenings. During the process of rapid elongation of the stem these elements are stretched out, the spirals or rings separated, and the thin, unpitted walls between the thickenings are likely to be torn and broken down. Such elements comprise that portion of the primary wood known as the *protoxylem*. The cells of the primary wood subsequently formed make up what is known as the *metaxylem*. The walls of the vascular elements of the metaxylem are thickened in a scalariform (ladder-like), reticulate (net-like), or pitted (dotted) manner.

The vessels (and tracheids) of the secondary wood are pitted, are without annular thickenings, and may or may not be spiral. The presence of spirals is a valuable diagnostic feature, and the vessels of smaller lumina exhibit them to best advantage. In a given wood all of the vessels may bear spirals or, especially where there is considerable variation in the size, only the smaller vessels may be thus marked. Conspicuously large vessels are invariably without spirals just as they are also without scalariform perforations.

Spirals exhibit considerable variation in distinctness. In some cases, as in *Ulmus*, they are very pronounced, in others, *e.g.*, *Tilia*, they are fine but distinct, and again they may be very fine and indistinct, as in *Magnolia*. In some instances, as previously stated, only the overlapping tips of the segments are spiral and these are often indistinct.

Tracheids which closely resemble vessel segments except in the absence of perforations, have the same markings as the vessels. Fibre-tracheids may also be spiral. This is normally the case in *Ilex* and occasionally in certain Rosaceæ, Ericaceæ, and others. The author has noted them in *Arbutus* and *Arctostaphylos*. Their presence provides a valuable diagnostic feature.

TABLE IX

Indigenous Woods with Spiral Markings in Part or in All of the Vessels

- ACERACEÆ
  - *Acer*
- ANACARDIACEÆ
  - Cotinus
  - Rhus
- ANONACEÆ
  - Asimina
- AQUIFOLIACEÆ
  - *Ilex*
- BETULACEÆ
  - *Carpinus*
  - *Ostrya*
- BIGNONIACEÆ
  - *Catalpa*
- BORAGINACEÆ
  - Ehretia
- CHEIRANTHODENDRÆ
  - Fremontodendron
- ERICACEÆ
  - Arbutus
  - Arctostaphylos
  - Andromeda
  - Kalmia
  - Oxydendrum
  - Rhododendron
  - Vaccinium
- HAMAMELIDACEÆ
  - *Liquidambar*
- HIPPOCASTANACEÆ
  - *Æsculus*
- LEGUMINOSÆ
  - Cercis
  - *Gleditsia*
  - *Gymnocladus*
  - *Robinia*
- LEITNERIACEÆ
  - Leitneria
- MAGNOLIACEÆ
  - *Magnolia*
- MELIACEÆ
  - Melia (Nat.)
- MORACEÆ
  - Broussonetia (Nat.)
  - *Morus*
  - *Toxylon*
- OLEACEÆ
  - Chionanthus
  - Osmanthus
- RHAMNACEÆ
  - Ceonothus
  - Rhamnus
- ROSACEÆ
  - Amelanchier
  - Aronia
  - Cercocarpus
  - *Prunus*
  - *Pyrus* (in part)
  - Rosa
  - Sorbus
- SCROPHULARIACEÆ
  - Paulownia (Nat.)
- SIMARUBACEÆ
  - Ailanthus (Nat.)
  - Koeberlinia
- TILIACEÆ
  - *Tilia*
- ULMACEÆ
  - *Celtis*
  - *Ulmus*
  - Planera

The vessels of secondary wood are always pitted. (See PITS, p. 31.) This feature is seen to best advantage in macerated material, especially where the vessels are so large that most of the wall is cut away in sectioning. The nature of the pitting is determined by the contiguous elements. The number, form, and arrangement of the pits on a given area of wall depends upon the particular kind of cell in contact there and the breadth of the surface of contact. The character of the pitting between adjacent vessels and between vessels and ray parenchyma is the most important for diagnostic purposes.

Pits between vessels are invariably bordered. The features worthy of special notice are the arrangement of the pits, the size and contour of the border, and the nature of the pit mouths. It is very common to find vessels in groups so compressed that the walls of mutual contact are flattened out broadly. In walls thus flattened it is not uncommon to find pits that are greatly elongated

transversely and arranged in a vertical series like the rungs of a ladder. This scalariform pitting is characteristic of the vessels in *Magnolia*, is common in *Liriodendron* and *Nyssa*, less so in *Liquidambar*, *Ilex* and *Platanus*, and of sporadic occurrence in *Castanea*, *Castanopsis*, *Quercus*, and some others. Since radial grouping is the most common, the pitted surfaces usually appear to better advantage in tangential than in radial sections.

Pits between vessels and ray cells are simple on the ray side but may be bordered, simple, or transitional on the other. These

TABLE X

NATURE OF PITTING OF VESSEL WALL WHERE IN CONTACT WITH RAY PARENCHYMA

FAMILY	Bordered	Simple	FAMILY	Bordered	Simple
Aceraceæ	X		Meliaceæ	X	
Anacardiaceæ		←—X	Moraceæ	X—→	
Anonaceæ	X		Myricaceæ	X	
Aquifoliaceæ	X		Myrsinaceæ	X	
Araliaceæ		←—X	Myrtaceæ	X—→	
Betulaceæ *	X	X	Nyctaginaceæ	X	
Bignoniaceæ	X—→		Oleaceæ	X	
Boraginaceæ	X		Platanaceæ	X	
Burseraceæ		←—X	Polygonaceæ	X	
Canellaceæ	X		Rhamnaceæ	X	
Capparidaceæ	X		Rhizophoraceæ	X—→	
Caprifoliaceæ	X——	——X	Rosaceæ	X	
Celastraceæ	X		Rubiaceæ	X	
Cornaceæ	X		Rutaceæ	X—→	
Cyrillaceæ	X		Salicaceæ		X
Ebenaceæ	X		Sapindaceæ	X	
Ericaceæ	X	X	Sapotaceæ	X——	——X
Euphorbiaceæ	X—→		Simarubaceæ	X—→	
Fagaceæ		←—X	Sterculiaceæ	X	
Hamamelidaceæ		←—X	Styraceæ	X	
Hippocastanaceæ	X——	——X	Symplocaceæ	X	
Juglandaceæ		X	Theaceæ	X——	——X
Koeberliniaceæ	X		Tiliaceæ	X	
Lauraceæ		←—X	Ulmaceæ	X	X
Leguminosæ †	X		Verbenaceæ	X	
Leitneriaceæ		X	Zygophyllaceæ	X	
Magnoliaceæ		←—X			

* In *Betula* and *Alnus* the pits are bordered; in *Carpinus*, *Corylus*, and *Ostrya* simple pits predominate.

† In *Robinia* the pits are predominately simple.

pits may be very small, medium or large, often with considerable variation in the same specimen. In woods with heterogeneous rays the marginal cells are usually more prominently pitted than the others. In *Gordonia* and *Oxydendrum* the pits are simple or only slightly bordered and are frequently in scalariform arrangement. In *Sideroxylon* and *Chrysophyllum* many of the pits are small and bordered while others are large, simple or nearly so, elliptical or elongated-elliptical and disposed horizontally, vertically or diagonally, resembling perforations rather than pits. In *Magnolia* it is common to find much elongated borders about groups of small pits.

Table X gives for the different families the dominant type of pits in vessels where in contact with the rays. Where both types are indicated with connecting line it refers to their occurrence side by side in the same wood; otherwise in different woods of same family. An arrow indicates transitions from the prevailing type.

VESSEL CONTENTS

The principal contents of vessels that have ceased to function actively as water-carriers are (*a*) tyloses (parenchymatous intrusions) and (*b*) various deposits or excretions such as gums, resins, lime, etc. Sometimes such features are constant and conspicuous enough to be of value for diagnostic purposes. In a great many cases, however, there is too much variation for dependable results. Generally it is merely a question as to whether the pores appear open or closed rather than exact determination by microscopic means of the presence or absence of certain contents. The feature is of most importance in woods with large pores.

The following table gives the results of some investigations by the author on the occurrence of tyloses and gum deposits in indigenous woods and a few that have been introduced. The findings do not in all cases agree with those of other investigators and in some instances are not to be considered as final, especially where non-occurrence is indicated, owing to the great likelihood of variation in different specimens.

TABLE XI

Occurrence of Tyloses and Gum Deposits in Vessels of Indigenous Woods

Genus	Tyloses	Gum	Genus	Tyloses	Gum
Acacia	few	common	Leitneria	absent	
Acer	absent	occasional	Liquidambar	common	
Æsculus	few	"	Liriodendron	"	
Ailanthus (Nat.)	absent	common	Magnolia	"	
Alnus	"		Melia (Nat.)	few	common
Amelanchier	"		Mohrodendron	absent	
Amyris	"	common	Morus	abundant	occasional
Anona	"		Nyssa	absent	common
Arbutus	"	common	Olneya	common	"
Arctostaphylos	"	"	Ostrya	absent	
Asimina	common		Oxydendrum	"	
Avicennia	absent		Parkinsonia	abundant	common
Betula	"	occasional	Paulownia (Nat.)	common	
Broussonetia (Nat.)	common	common	Persea	"	
Bumelia	"		Planera	absent	
Bursera	absent		Platanus	few	
Carpinus	"		Populus	common	
Castanea	abundant		Prosopis	absent	common
Castanopsis	common		Prunus	"	"
Catalpa	abundant		Ptelea	common	
Celtis	common		Pyrus	absent	
Cercidium	absent		Quercus (white)	abun-few	
Cercocarpus	"		" (red)	few-abun.	
Chilopsis	abundant		" (live)	"	
Cladrastis	absent	common	Rhamnus	absent	common
Cornus	"		Rhizophora	"	
Cotinus	abundant	common	Rhododendron	absent	
Cratægus	absent		Rhus	abundant	common
Diospyros	"		Robinia	abundant	
Eucalyptus (Int.)	common	common	Salix	common	
Fagus	"		Sambucus	"	
Ficus	abundant		Sapindus	absent	common
Fraxinus	abun-few	rare	Sassafras	common	
Fremontodendron	absent		Swietenia	absent	
Gleditsia	"	common	Symplocos	"	
Guaiacum	"	"	Tilia	"	
Gymnocladus	"	"	Toxylon	abundant	common
Hamamelis	"		Ulmus	few-abun.	
Hicoria (Carya)	abundant		Umbellaria	absent	
Ilex	absent		Vaccinium	"	
Juglans	abundant		Viburnum	"	common
Kalmia	absent		Xanthoxylum	absent	occasional

RING-POROUS AND DIFFUSE-POROUS WOODS

There are 36 indigenous genera, exclusive of shrubs and vines, with ring-porous woods, at least in part, and 4 that have become thoroughly naturalized in the United States. These 40 genera are representatives of 20 families of which only four, each consisting of a single genus, are exclusively ring-porous. Sixteen of these genera supply wood of more or less economic importance. In the case of *Quercus* the live oaks are mostly diffuse-porous, while one species of *Hicoria* and one or two of *Ulmus* are rather intermediate, at least in certain instances. Some species of *Prosopis* are diffuse-porous and some other genera, *e.g.*, *Leitneria* and *Ptelea*, produce woods which require rather close observation to note their ring-porous nature.

There are 35 families whose indigenous representatives are exclusively diffuse-porous. Eleven of these families include 15 genera of economic woods. Of a total of 147 indigenous dicotyledonous woods, 113 or nearly 80 per cent are diffuse-porous. Insofar as the economic woods are concerned, however, the division is about equal.

TABLE XII

Families with Indigenous Representatives Exclusively Diffuse-porous

Aceraceæ	Cornaceæ	Platanaceæ
Aquifoliaceæ	Cyrillaceæ	Polygonaceæ
Betulaceæ	Ericaceæ	Rhamnaceæ
Boraginaceae	Euphorbiaceæ	Rhizophoraceæ
Burseraceæ	Hamamelidaceæ	Rosaceæ
Canellaceæ	Hippocastanaceæ	Salicaceæ
Capparidaceæ	Koeberliniaceæ	Styraceæ
Caprifoliaceæ	Magnoliaceæ	Symplocaceæ
Caricaceæ (?)	Myricaceæ	Theaceæ
Celastraceæ	Myrsinaceæ	Theophrastaceæ
Combretaceæ	Myrtaceæ	Tiliaceæ
	Nyctaginaceæ	Zygophyllaceæ

TABLE XIII

Indigenous Ring-porous Woods

Acacia	Cotinus	Paulownia (Nat.)
Ailanthus (Nat.)	Dalea	Parkinsonia
Asimina	Diospyros	Pinckneya
Avicennia	Ehretia	Prosopis
Broussonetia (Nat.)	Eysenhardtia	Ptelea
Bumelia	Fraxinus	Quercus
Castanea	Fremontodendron	Rhamnus
Castanopsis	Gleditsia	Rhus
Catalpa	Gymnocladus	Robinia
Celtis	Hicoria (Carya)	Sapindus
Cercis	Leitneria	Sassafras
Chilopsis	Melia (Nat.)	Sophora
Chionanthus	Morus	Toxylon
		Ulmus

TABLE XIV

Nature of Pitting in Wood Fibres of Indigenous Woods

Genus	Simple	Bordered	Genus	Simple	Bordered
Acacia	X		Juglans		X
Acer		X	Kalmia		X
Æsculus		←X	Leitneria	X	
Ailanthus (Nat.)	X		Liquidambar		X
Alnus		X	Liriodendron		X
Amelanchier		X	Magnolia		X
Amyris		←X	Melia	X	
Andromeda		X	Mohrodendron		X
Anona	X		Morus	X	
Arbutus	X→		Myrica		X
Arctostaphylos	X→		Nyssa		←X
Asimina	X		Ocotea	X	
Avicennia	X		Olneya	X	
Betula		X	Ostrya		X
Broussonetia (Nat.)	X		Oxydendrum		X
Bumelia	X		Parkinsonia	X	
Bursera	X		Paulownia (Nat.)	X	
Carpinus		X	Persea	X	
Castanea		X	Planera	X	
Castanopsis		X	Platanus		X
Catalpa	X		Populus	X	
Ceanothus	X		Prosopis	X	
Celtis	X		Prunus		X
Cercis	X		Ptelea	X	
Cercocarpus	X		Pyrus		X
Chilopsis	X		Quercus		X
Chionanthus		X	Rhamnus	X	
Chrysophyllum	X→		Rhizophora	X	
Cladrastis	X		Rhododendron		X
Cornus		X	Rhus	X	
Cotinus	X		Robinia	X	
Cratægus		X	Salix	X	
Cyrilla		X	Sambucus	X	
Diospyros		X	Sapindus	X	
Eucalyptus (Int.)		X	Sassafras	X	
Fagus		X	Sideroxylon	X	
Ficus	X		Swietenia	X	
Fraxinus	X→		Symplocos		X
Fremontodendron	X		Tilia		←X
Gleditsia	X		Toxylon	X	
Gordonia		X	Ulmus	X	
Guaiacum		X	Umbellaria	X	
Gymnocladus	X		Vaccinium		X
Hamamelis		X	Viburnum		X
Hicoria (Carya)		X	Xanthoxylum	X	
Ilex		X			

Arrows indicate transitions from the prevailing type.

TABLE XV

Kinds of Rays in Indigenous Dicotyledonous Woods

Genus	Homogeneous	Heterogeneous	Genus	Homogeneous	Heterogeneous
Acacia	X		Juglans	X ⟶	
Acer	X		Kalmia		X
Æsculus		⟵ X	Leitneria		X
Ailanthus (Nat.)		X	Liquidambar		X
Alnus	X		Liriodendron		X
Amelanchier		X	Magnolia		X
Amyris	X		Melia (Nat.)		X
Andromeda		X	Mohrodendron		X
Anona		⟵ X	Morus		X
Arbutus		X	Myrica		X
Arctostaphylos		X	Nyssa		X
Asimina		X	Ocotea		X
Avicennia		X	Olneya	X	
Betula	X		Ostrya		X
Broussonetia (Nat.)		X	Oxydendrum		X
Bumelia		X	Parkinsonia	X	
Bursera		X	Paulownia (Nat.)		X
Carpinus	X		Persea		X
Castanea		⟵ X	Planera		X
Castanopsis		⟵ X	Platanus	X	
Catalpa	X ⟶		Populus	X	
Ceanothus		X	Prosopis	X	
Celtis		X	Prunus		⟵ X
Cercis	X		Ptelea		
Cercocarpus	X		Pyrus	X	
Chilopsis		X	Quercus	X ⟶	
Chionanthus		⟵ X	Rhamnus		⟵ X
Chrysophyllum		X	Rhizophora		X
Cladrastis	X		Rhododendron		X
Cornus		X	Rhus	X	
Cotinus		X	Robinia	X ⟶	
Cratægus	X ⟶		Salix		X
Cyrilla		X	Sambucus		X
Diospyros		X	Sapindus	X	
Eucalyptus (Int.)	X ⟶		Sassafras		X
Fagus		⟵ X	Sideroxylon		X
Ficus	X		Swietenia		X
Fraxinus	X		Symplocos		X
Fremontodendron		X	Tilia	X	
Gleditsia	X		Toxylon	X ⟶	
Gordonia		X	Ulmus	X	
Guaiacum	X		Umbellaria	X ⟶	
Gymnocladus	X		Vaccinium		X
Hamamelis		X	Viburnum		X
Hicoria (Carya)	X ⟶		Xanthoxylum		X
Ilex		X			

Arrows indicate transitions from the prevailing type.

TABLE XVI

Indigenous Woods with "Ripple Marks"

Species	No. per inch	Remarks
Æsculus octandra	58–68	Lines often wavy
Artemisia tridentata	200	Shrub; rays not storied
Baccharis sarathoides	120–128	" " " "
Biglovia graveolens	200	" " " "
Cercis canadensis	150–160	Many rays 2-storied
Crescentia curcubitina	110–115	Lines irregular
Dalbergia brownei	120	Shrub; marks visible
Dalea spinosa	150	Rays not storied
Diospyros virginiana	55–80	Lines usually wavy
Guaiacum sanctum	250	Invisible without lens
Olneya tesota	150–160	Distinct only in inner bark
Simaruba glauca	50–55	Often irregular
Sophora secundiflora	160	Rays not storied
Swietenia mahagoni	45–55	Often absent
Tilia americana	55–60	Rays not storied
" heterophylla	55–60	" " "
" pubescens	55–60	" " "

INDEX

DESCRIPTION OF PLATES

All photomicrographs (except frontispiece) show magnification of 50 diameters.

PLATE I.

DESCRIPTION OF PLATE I.

Map of the United States showing Natural Forest Regions.

Map of the United States showing Natural Forest Regions. (U. S. Forest Service.)

PLATE II.

DESCRIPTION OF PLATE II.

FIG. 1.—*Taxodium distichum* (bald cypress): cross section through portions of two growth rings. Several resin cells are visible near the lower edge.

FIG. 2.—*Tsuga canadensis* (eastern hemlock): cross section. Note decided contrast between early and late wood.

FIG. 3.—*Juniperus virginiana* (red cedar): cross section through median portion of growth ring showing zonate arrangement of resin cells.

FIG. 4.—The same: cross section showing very thin late wood; also doubling of the late wood, producing "false ring." Note small size of tracheids.

FIG. 5.—*Quercus alba* (white oak): cross section showing small pores with thin walls and angular outlines and in broad band; large pores with tyloses.

FIG. 6.—*Quercus rubra* (red oak): cross section showing small pores with thick walls and circular outlines, and in narrow band; large pores without tyloses.

PLATE II.

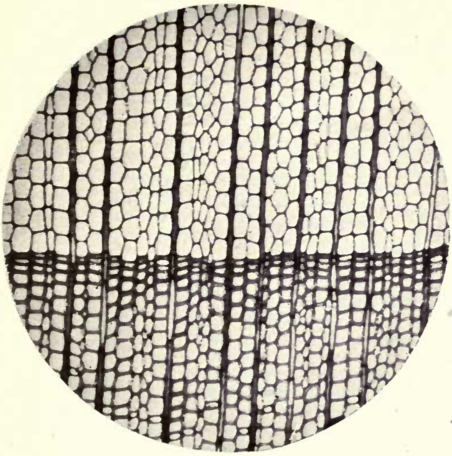


Fig. 1

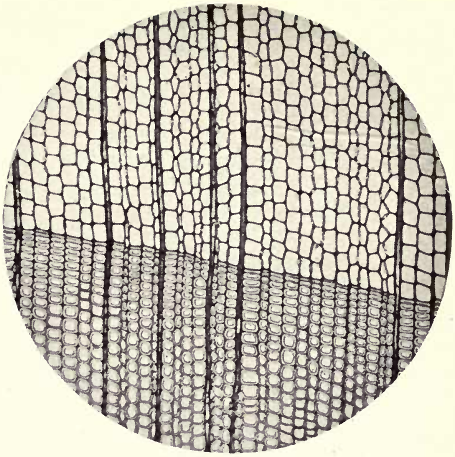


Fig. 2

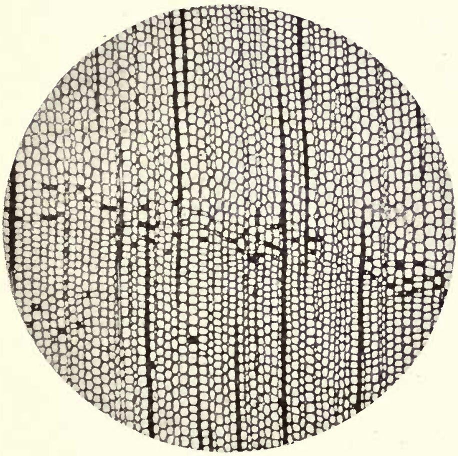


Fig. 3

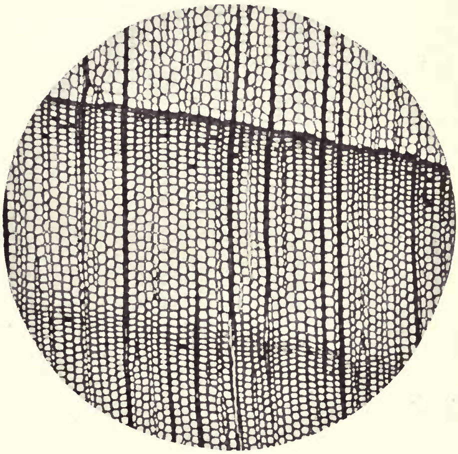


Fig. 4

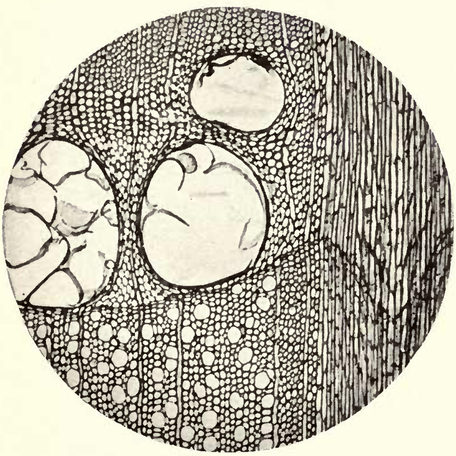


Fig. 5

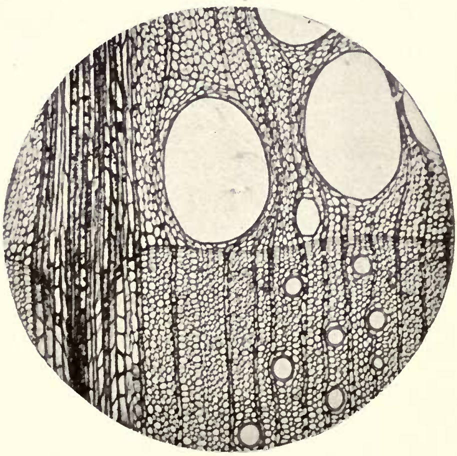


Fig. 6

PLATE III.

DESCRIPTION OF PLATE III.

FIG. 1.—*Quercus alba* (white oak): tangential section showing end of large ray and numerous small uniseriate rays, separated by wood fibres, and occasional wood-parenchyma strands.

FIG. 2.—*Ulmus americana* (American elm): cross section showing the largest pores in a single row, the small pores in wavy tangential bands.

FIG. 3.—*Robinia pseudacacia* (black locust): cross section showing arrangement of pores and parenchyma, and very dense wood fibres in late wood; pores in early plugged with tyloses and separated by abundant wood parenchyma and tracheids.

FIG. 4.—*Toxylon pomiferum* (Osage orange): radial section showing tyloses in vessels; wood-parenchyma strands, tracheids and dense wood fibres; and heterogeneous ray.

FIG. 5.—*Gymnocladus dioicus* (Kentucky coffee tree): cross section showing comparatively large, thin-walled pores in late wood.

FIG. 6.—*Gleditsia triacanthos* (honey locust): cross section showing minute, thick-walled pores in late wood. Growth ring limited by rather wide zone of wood parenchyma.

PLATE III.

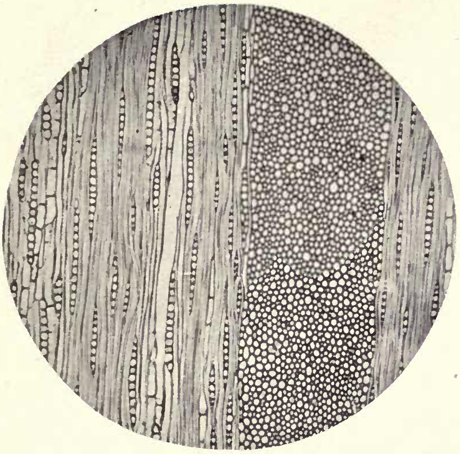
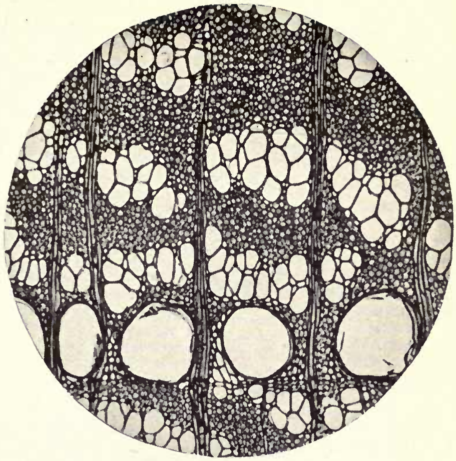


Fig. 1



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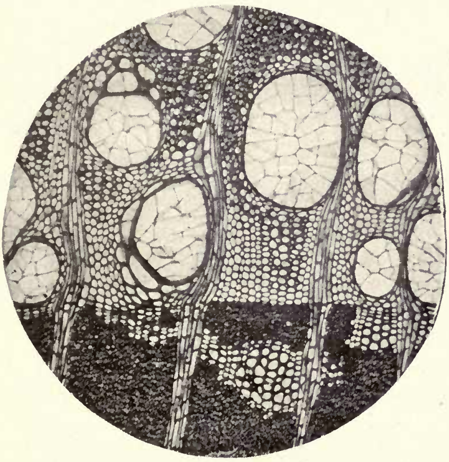

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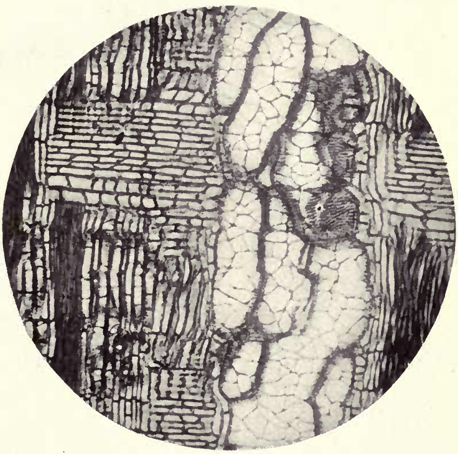

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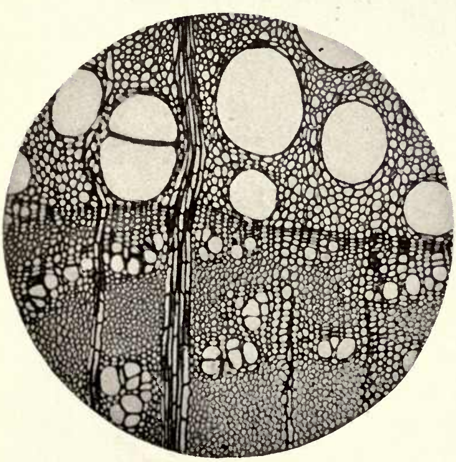

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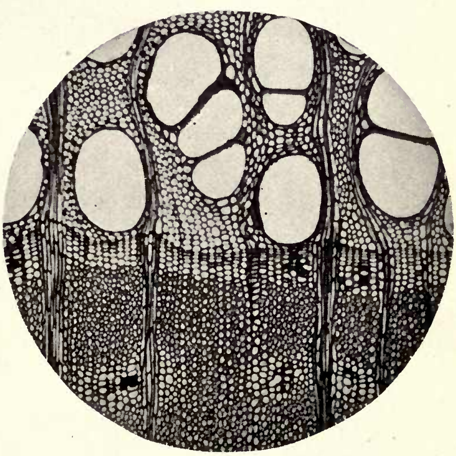


Fig. 6

PLATE IV.

DESCRIPTION OF PLATE IV.

FIG. 1.—*Hicoria ovata* (shagbark hickory): cross section showing very thick-walled wood fibres and distinct tangential lines of wood parenchyma; large pores with tyloses.

FIG. 2.—*Diospyros virginiana* (persimmon): cross section showing rather indistinct tangential lines of wood parenchyma; pores without tyloses.

FIG. 3.—*Hicoria pecan* (pecan hickory): tangential section showing very irregular rays, three large calcium-oxalate crystals, and numerous wood-parenchyma strands.

FIG. 4.—*Diospyros virginiana:* tangential section showing fairly uniform rays in storied arrangement. Crystals visible, but very small.

FIG. 5.—The same; radial section showing vessel segments, heterogeneous rays, wood-parenchyma strands, and wood fibres in storied arrangement.

FIG. 6.—*Juglans nigra* (black walnut): radial section showing rays, large vessel with tyloses, wood-parenchyma strands, chambered-parenchyma cells with crystals, and wood fibres.

PLATE IV

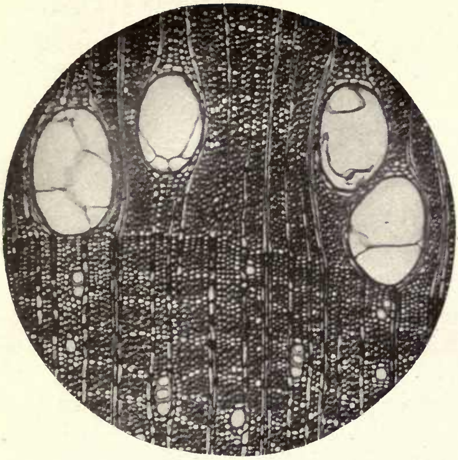
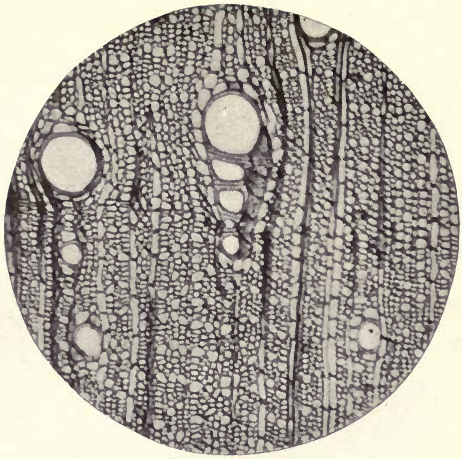


Fig. 1



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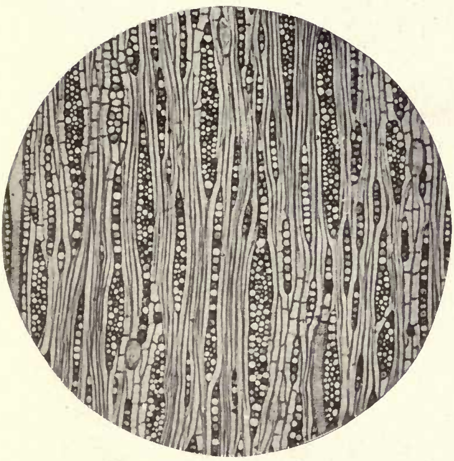

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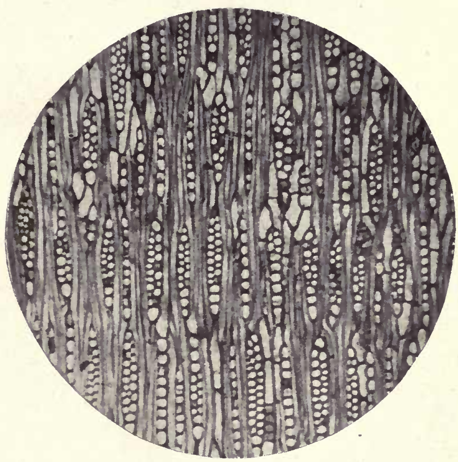

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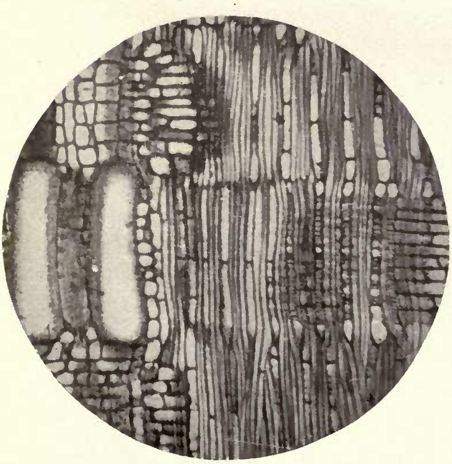

Fig. 5

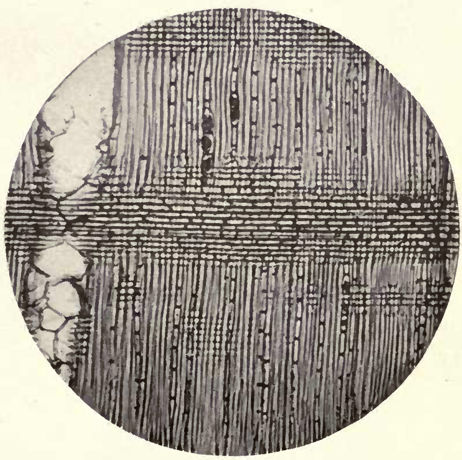

Fig. 6

PLATE V.

DESCRIPTION OF PLATE V.

FIG. 1.—*Morus rubra* (red mulberry): cross section showing arrangement of pores in late wood, width of rays, and presence of tyloses in large pores.

FIG. 2.—*Fraxinus nigra* (black ash): cross section showing isolated pores in late wood not joined tangentially by wood parenchyma. Outer margin of growth ring composed of thin layer of wood parenchyma.

FIG. 3.—*Alnus oregona* (red alder): cross section showing aggregate ray and distribution of pores.

FIG. 4.—The same: tangential section showing aggregate ray, intermediate uniseriate rays, vessels, wood fibres, and wood-parenchyma strands.

FIG. 5.—*Betula lenta* (sweet or black birch): cross section showing size and distribution of pores and width of rays. Note wood-parenchyma cells, isolated or in short tangential lines.

FIG. 6.—*Ostrya virginiana* (hornbeam): cross section showing size and arrangement of pores and distribution of wood-parenchyma cells in inconspicuous tangential lines.

PLATE V

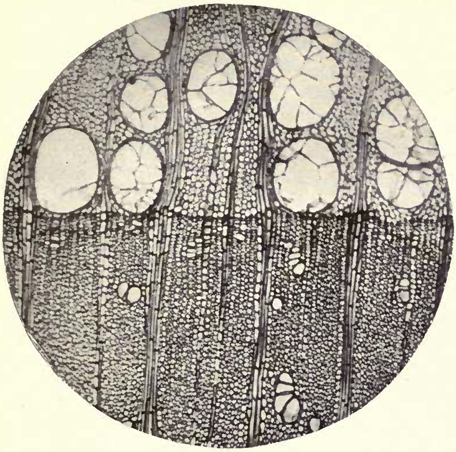

Fig. 1

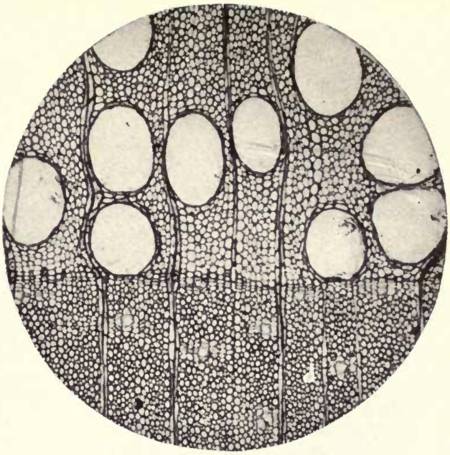

Fig. 2

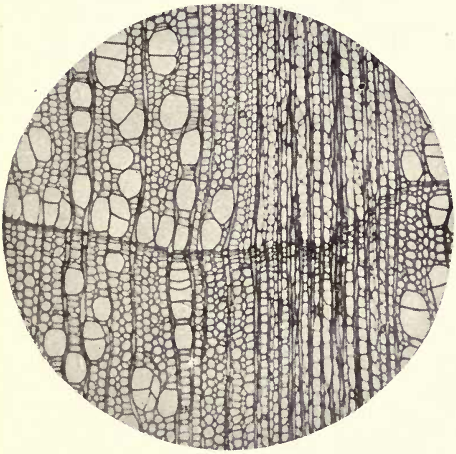

Fig. 3

Fig. 4

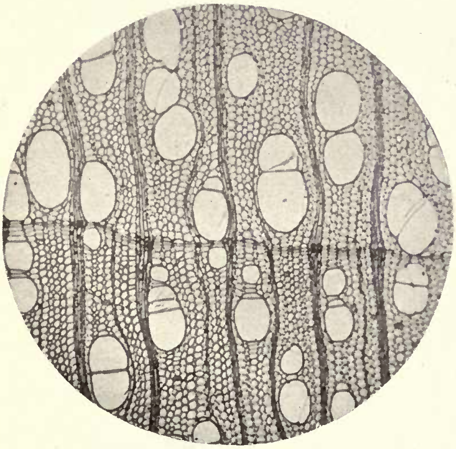

Fig. 5

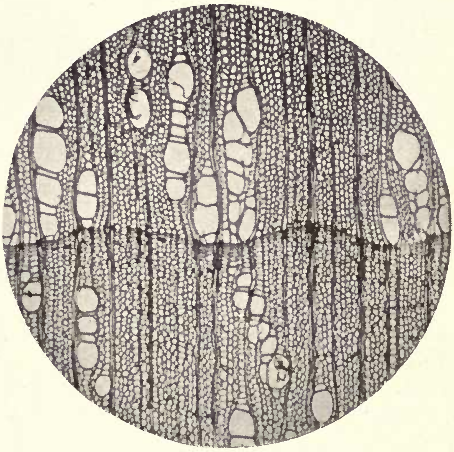

Fig. 6

PLATE VI.

DESCRIPTION OF PLATE VI.

FIG. 1.—*Liquidambar styraciflua* (red or sweet gum): cross section showing size and distribution of pores, width of rays, and arrangement of wood fibres in radial rows.

FIG. 2.—*Liriodendron tulipifera* (yellow poplar or tulip-tree): cross section showing size and distribution of pores, and thin layer of wood-parenchyma cells marking outer limit of growth ring.

FIG. 3.—*Magnolia acuminata* (cucumber tree): tangential section showing vessels with scalariform bordered pits, and the small biseriate rays.

FIG. 4.—*Liriodendron tulipifera:* tangential section showing vessels with ordinary bordered pits, and the comparatively large 3–5-seriate rays.

FIG. 5.—*Æsculus glabra* (Ohio buckeye): cross section showing uniform distribution of pores and rays.

FIG. 6.—The same: tangential section showing very fine uniseriate rays, irregularly disposed.

PLATE VI

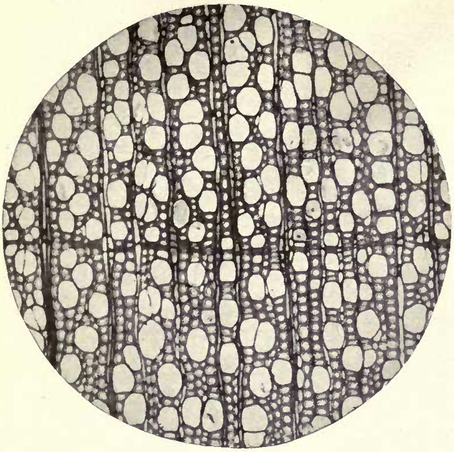

Fig. 1

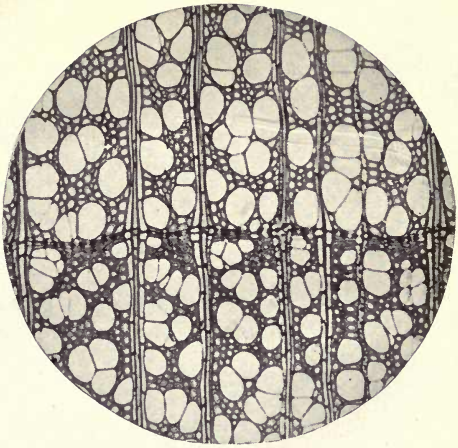

Fig. 2

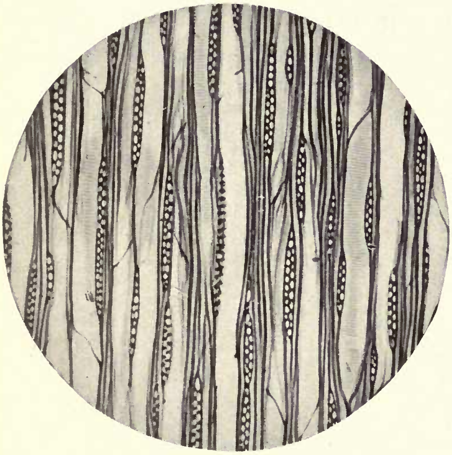

Fig. 3

Fig. 4

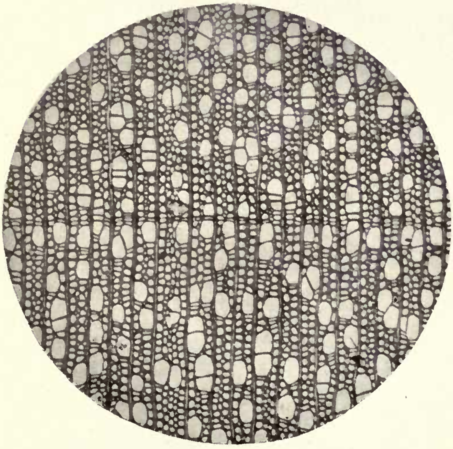

Fig. 5

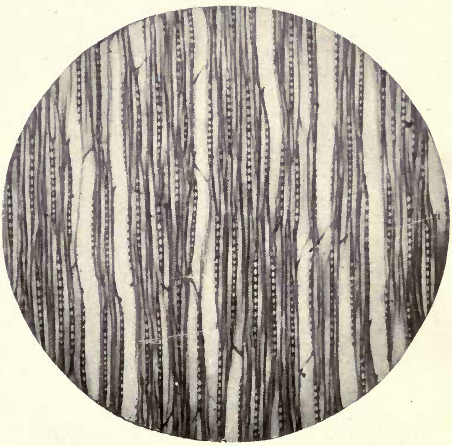

Fig. 6